STUDIES ON SULPHUR AND ZINC IN SOIL-PLANT RELATIONSHIP

A

THESIS

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By

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ALLAHABD

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Dedicated

To

My Venerable Parents

SHEILA DHAR INSTITUTE OF SOIL SCIENCE

University of Allahabad

(Established in 1935)

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CERTIFICATE

This is to certify that Sri Man Mohan Lal, M.Sc. (Ag. Chem. & Soil Sci.) has conducted research work under my supervision on the topic entitled "Studies on Sulphur and Zinc in Soil-Plant Relationship" for the award of the degree of Doctor of Philosophy in Agricultural Chemistry and Soil Science, of the Allahabad University. Experimental observations and data presented in the thesis to the best of my knowledge are genuine and original.

Dated: 23rd December 2002

Allahabad

Mmverma

(M.M. VERMA)

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INTRODUCTION

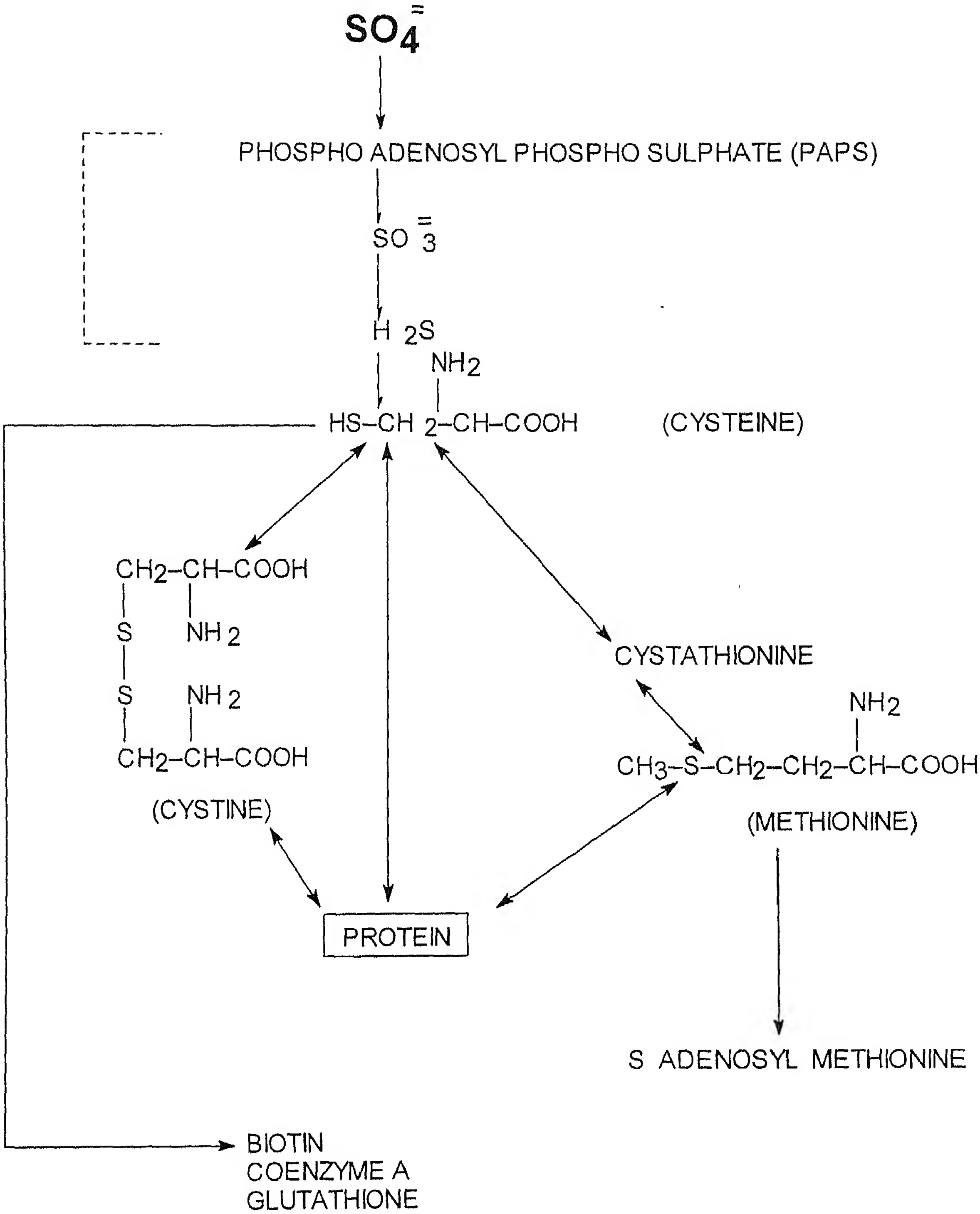

FIG. 1 SOME METABOLIC PATHWAYS OF S IN PLANTS

(e) The formation of certain disulphide linkage that have been associated with the structural characteristics.

(f) In some species the concentration of sulphydryl (-SH) groups in plant tissue has also been shown to be related to increased cold resistance.

(g) Formation of chlorophyll.

(h) Formation of ferredoxin, an iron containing plant protein that functions as an electron carrier in photosynthetic processes.

(i) Formation of ferredoxin like compound which is involved in the fixation of N by root nodule bacteria and free living N-fixing soil bacteria; and

(j) Activity of ATP sulphurylase, as enzyme that functions in the metabolism of S.

Before the introduction of high yielding fertilizer responsive varieties of crops in 1960, S deficiency was not wide spread. In the late 1960s some areas started showing S deficiency and currently deficiency is widespread. This attracted widespread attention of the experts. However, the interesting point to be noted here is that while reports of S deficiency and crop response to its use are increasing, the addition of sulphur through traditional S-containing fertilizers (ammonium sulphate, SSP etc) is decreasing. The consumption of SSP, which has been the largest S source to the crops, in 1991 was 3558 thousand tons, while it was 3535 thousand tons in 2000, continuous increase in cropping intensity increased the sulphur uptake by crops. Losses of S through leaching and erosion, and use of high analysis S free fertilizers etc. are the major contributing factors to the increasing deficiency in the country.

Sulphur has been recognized as the fourth major essential plant nutrient, because of its wide spread deficiencies in many crops. The yield has come to stagnation despite our best efforts to breed high yielding pest and disease resistant varieties and adoption of improved crop management practices its deficiency is posing serious threats in realization and stabilization of potential yields of several crops not only in marginal lands but also in well fertile soils. The gap in sulphur supply and its removal by crops has become to 2.0 million tons. It is unfortunate that in spite of extensive sulphur deficiencies reported in Indian soils, its rate in balanced nutrition point of view has been ignored both from crop yield and human nutrition. All the policy decision remain centered around in promoting more and more use of high analysis NPK fertilizers free from sulphur.

The Sulphur in arable soils occurs mostly in organic forms and partially in inorganic forms, the supply of S to plants in a given soil, depends upon inorganic sulphate content of the soil and the rate of mineralization of organic S. The term available S includes water soluble S and adsorbed S and easily hydrolysable organic S compounds. The fractions of inorganic S present in each of these states depend on several soil properties and climatic conditions. No comprehensive study of S status has been done with respect to agro-ecological regions of the country.

While working on S status in Indian soils, workers generally concentrated on five different forms of S viz. water soluble S (WS-S), available S, heat soluble organic S, non So_4- S and total summary of the status of available S in different agro-ecological regions of Uttar Pradesh as mentioned in fertilizer News of May, 1999 gives a clear cut picture of the available S in alluvial soils of the state.

Table 1.1: Sulphur status of soil in different agro ecological region of U.P.

Agro-ecological regions /State /District	Soil/Soil group	No. of soils	Water soluble-S	Available S		Heat soluble S ppm	Organic sulphate S ppm	Non-sulphate S ppm	Total S ppm
				Range	Mean				
Agra	Alluvial	170	4.5-25.5	3.0-32.5	11.9	-	-	-	40-165
Aligarh and Mathura	Alluvial	20	34.1	10.0-32.5	22.7	-	43.8	89.4	156
Farrukhabad	Alluvial	45	22.2	14.8-32.0	23.2	25.8	30.0	87.6	141
Kanpur	Alluvial	114	20.6	3.0-37.5	13.3	-	41.4	75.7	133
Lucknow	Alluvial	20	-	12.7-67.4	23.1	-	-	-	-
Kanpur, Aligarh, Mathura	Alluvial (rice soils)	22	36.0	8.0-24.0	15.0	28.0	41.0	-	104-179
Jaunpur, Kanpur Agra Aligarh	Alluvial	8	24.0	15.0-20.0	17.5	26.7	38.0	91.0	153
Jhansi	Alluvial	4	19.1	4.9-13.5	11.3	26.7	46.2	94.8	153
Varanasi	Ustifluvents	36	2.8-30.5	2.4-42.0	16.0	17.6-49.2	-	-	-
Moradabad	Ustifluvents	120	-	7.5-56.2	34.6	-	-	-	-

Ref.: Fert. - News May 1999.

In India, S- deficiencies are found in almost 40% of the cultivated area (Tandon 1995). Different crop species have different S-requirement of all the crops, brassica species like rapeseed, mustard, cabbage, turnips, etc. have highest S requirement followed by legumes such as berseem, clovers, groundnut and soybean. Cereals have the least requirement of this element. In general, oilseed crops have more S requirement than other crops. Irrespective of total S needs, this element is needed for making efficient use of other fertilizer-nutrients.

Zinc in one of the seven micro nutrients and was the first one to be recognized as essential for plants. It is the micronutrient most commonly limiting crop yields. The important functions of zinc in plants are:

(a) It is required for production of chlorophyll.

(b) It aids in synthesis of plant growth substances and several enzymes that regulate various metabolic activities in plant systems.

(c) It is vital for processes of oxidation in the plant cells.

(d) It helps in production and transformation of carbohydrates.

(e) It regulates consumption of sugars.

(f) Zinc shortage retards photosynthesis and nitrogen metabolism.

(g) Zinc deficiency inhibits uptake of water causing stunting of growth.

Zinc is involved in many enzymatic activities, but it is not known whether it acts as a functional, structural, or regulatory cofactor. Zn is important in the synthesis of tryptophan, a component of some proteins and a compound needed for the production of growth hormones (auxins) like indole acetic acid. Reduced growth hormone production in Zn deficient plants causes the shortening of internodes and smaller than normal leaves.

Response to Zn differed widely among the crops in each state as well as among the states for each crop because of wide differences in the sensitivity of crops to Zn, the number of experiments conducted in each state as well as in the degree of deficiency in soils on which the test was performed. For examle, the responses would be very high if the experiments are conducted on soils with unknown Zn status, as is done under the ICAR All India coordinated Agronomic Research project (Experiments at cultivators, Fields -ECF) This means that real comparisons are not possible. Nevertheless, some generalization could be made for crops where adequate number of experiments were conducted.

Large number of field experiments (4807) were conducted by the centers of the Micronutrient project in different states of India to assess the response of cereals, pulses, oil seeds, vegetables, cash crops etc.

Response of Zn as high as 47-48 q ha^{-1} of wheat and rice and 20 q ha^{-1} of maize was obtained on soils severely deficient in Zn. But the range of the mean value for various crops was : cereals 2.5-14.8 q ha^{-1}, millets 1.7-6.0 q ha^{-1}, pulses 0.5-11.2 q ha^{-1} and oilseeds 1.2-4.7 q ha^{-1} However, the overall average response range in crops was: cereals 3.6 q ha^{-1} of wheat to 5.5 q ha^{-1} of barley, millets 1.7 q ha^{-1} of pearl millet to 3.6 q ha^{-1} of finger millet, pulses 1.6 q ha^{-1} of pigeon pea to 4.6 q ha^{-1} of peas, oilseeds 1.1 q ha^{-1} of sesamum to 3.2 q ha^{-1} of groundnut

Although Zn and S deficiencies have been reported in many soils, yet a relationship between the two is not clear and has not been studied much. While Shukla and Parsad (1979) at Hisar center found an antagonistic relationship between S and Zn in groundnut, it was shown to be synergistic by Bahl et al. (1986) at Ludhiana center as application of one increased the uptake of the other. Synergistic effect of these two nutrients on yield and their concentration in wheat grown in a Sand Zn-deficient soil of Haryana was also shown by Hisar centre (Annual report 1984). Application of S or Zn individually increased the dry matter yield successively and significantly upto 3ppm level of Zn. The combined application of 5 ppm Zn and 80 ppm S also produced the maximum yield.

As the N P K use to achieve high production targets will have to be increased sulphur and zinc demands of the crops commensuration with N P K

consumption will automatically increase. Keeping these facts in view and also paucity of information the present investigation entitled "Studies on sulphur and zinc in soil plant relationship" was initiated with the following objectives:-

(1) Distribution of sulphur and zinc in some soils of Allahabad and Fatehpur district for assessment of S and Zn levels. (Laboratory experiment).

(2a) To study the response of S and Zn application in mustard in a field trial on yield and attributing characteristics.

(2b) S-uptake, Zn-uptake and oil content in mustard grains.

(2c) Effect of different treatments on soil after harvest of the crop.

(3a) To study response of S and Zn application in chickpea crop in a field trail on yield and yield attributing characteristics.

(3b) Uptake of N, P, K, S and Zn by chickpea crop and protein content in grains.

(3c) Effect of different treatments on soil after harvesting.

CHAPTER-II

REVIEW OF LITERATURE

doses of S and Zn on yield, uptake of nutrients and quality of mustard (Brassica compestris) var. toria and chickpea (Cicer arietinum L.).

(a) Sulphur In Soil And Plants:

Rathore and Maliwal (1990) have conducted a field trial with mustard [*Brassica juncea*] grown on a S-deficient soil, applying 250 kg elemental S, gypsum or ferrous sulphate/ha (212.5, 45.0 and 45.0 kg S/ha, resp.) before sowing gave seed yields of 3.01, 2.88 and 2.72 t/ha respectively, compared with 2.69 t/ha without S. A foliar application of 0.5% zinc sulphate or ferrous sulphate or 0.1% sulphuric acid had no significant effect on yields.

Bandyopadhyay et al. (1995) reported that sulphur play a significant role in determining the productivity of mustard in red and lateritic soils. However, information regarding availability of this element in such soils are very meagre and lack of knowledge on suitability of various methods of available sulphur estimation restricts detailed studies on this aspect. Taking this problem into consideration, the relative efficiency of different methods of available sulphur estimation in red and lateritic soils were assessed in relation to mustard cultivation. Out of five procedures tested, Morgan's method using N NaOAC+HOAC (pH 4.8) appeared to be closely correlated with mustard yield.

Khurana et al. (1995) conducted a field experiment in which *B. juncea* cv. RLM 619 grown in farmers fields in 10 villages in Punjab in 1987-93 and was given 0, 20 or 40kg S/ha. Seed yield averaged 1.08, 1.34 and 1.42 t/ha with the 3 S doses, respectively. Yield response at the higher

S rate ranged from 3 to 96% at the different sites. Yield response was negatively correlated with available soil S, and it is suggested that S should not be applied to *B. juncea* in soils with >10.2 p.p.m. of 0.15% $CaCl_2$ extractable S.

Kulhare et al. (1996) conducted a field trial in winter of 1987-88 at Powarkheds India, Linum usitatissimum cv. JLS23 was given 0, 15 or 45kg S/ha as single superphosphate (SSP) or ammonium sulfate or 15kg S/ha as 10Kg SSP+5Kg $ZnSO_4$, $MgSO_4$, $MgSO_4$ or $FeSO_4$. Seed yield was highest with 45 kg S/ha as SSP which gave a 49.5% increase in seed yield over the untreated control. Application of 15 kg S/ha as SSP+$MnSO_4$ gave significant higher yields than the same rate of S applied as ammonium sulfate.

Singh et al. (1997) conducted a field experiment in which summer moong was grown in two years with application of elemental sulphur (0, 15, 30 and 45 kg ha^{-1}) on Inceptisol (Udic Ustochrept). Sulphur application improved significantly plant biomass, nodule number and seed weight and straw yield, nitrogen and sulphur uptake and optimum being 30 kg ha^{-1} application of sulphur upto 15 kg ha^{-1} increased population of total bacteria and Azotobacter. However, addition of sulphur decreased the population of fungi and actinomycetes.

Sharma and Gangwar (1997) reported that organic heat soluble and calcium chloride extractable-S were correlated significantly and positively with organic carbon and total N. Multiple regression equations were worked out for predicting different forms of sulphur from soil properties viz. pH, electrical conductivity, organic carbon and total N.

Chouliaras and Tsadilas (1998) carried out the effectiveness of elemental S to reduce soil pH and the consequences of applications of 0-2 g S/kg soil on the availability of K, P, Fe, Zn, Mn and Cu were investigated on a calcareous soil (Typic xerofluvent) in a pot experiment in which Kiwifruit was grown. Sulphur application significantly affected all the properties studied. Soil pH was reduced by 1.8 units. Organic P was significantly reduced while inorganic P increased probably due to the favourable conditions for microbial activity created by soil pH reduction exchangeable-K increased from 0.183 to 0.33 C mol/Kg, and metal concentrations increased significantly. However, the increase in Fe concentrations was insufficient for crop requirements, whereas Cu and Mn increased above the recommended level. There was a significant negative correlation between metal concentration and soil pH, the highest being for Mn.

Gupta and Dubey (1998) studied the paper reviews on available information to the extent and degree of S-deficiency and distribution of available S in the state of Madhya Pradesh India sulphur concentrations and requirement of crops. Crop response to S application, direct and residual effect of S in different cropping systems, interaction of S with N, P, Zn and Mo, impact of S fertilization on N_2-fixation and water use efficiency were also examined.

Kaplan and Orman (1998) studied the effect on soil pH of application of 0-2000 kg ha^{-1} of elemental sulphur and 0-100 t ha^{-1} of S-containing waste was determined in a field (in Turkey) and in pots. Sorghum (Sorghum bicolor) was grown in a Lithic Xerorthent soil. Plants

were harvested 20 weeks after sowing or 30 weeks after the application of S or waste for the determination of dry matter yield and P, Fe, Zn, Mn and Cu uptake by shoots. EC, $NaHCO_3$-extractable P and DTPA-extractable Fe, Zn, Mn, Cu also were measured in pot soil 5, 10 and 30 weeks after sowing. All treatments led to a decrease in soil pH though pH tended to increase again over time in both field and pot experiments. Elemental S and waste applications in pots increased dry matter yield and uptake of P, Fe, Zn, Mn and Cu. There was also an increase in EC of soil due to both S treatments. The concentration of available P extracted by $NaHCO_3$ in the pot soil, though not significantly different, was slightly higher as compared with the control. Waste applications increased DTPA-extractable Fe, Mn and Cu contents but decreased Zn content.

Khare and Sharma (1998) studied in a field at Sagar, Madhya Pradesh, India in the 1988 and 1989 rainy seasons, soyabeans cv. JS-72-44 and JS-75-46 were given S as gypsum, single superphosphate or zinc sulphate (each at 10 kg S/ha) or by foliar spraying (0.5%) of elemental S or micron-S. Seed yield was higher in cv. JS-72-44 in 1988 and in JS-75-46 in 1989. Mean yield was 1.33 t/ha without S fertilizer and 1.50-1.68t in S treatments, yield was highest when S was sprayed as micron-S.

Patra et al. (1998) conducted a green house experiment to study the effect of sulphur application and five water management practices on mineral nutrition, growth and yield of rice in six different S-deficient wetland rice soils. Under continuously flooded condition rice plants showed characteristic S-deficiency symptoms and produced lowest grain yield and dry matter. Application of fertilizer S or soil drying for-2 weeks

during active tilliering or panicle initiation stage and reflooding increased crop yield by eliminating S-deficiency. Soil drying and reflooding influenced Mg, S, Fe, Mn, Zn and Cu nutrition of rice, favourably which together accounted for 89% variability in rice grain yield.

Singh et al. (1998) conducted a field experiment during winter (rabi) 1994/95 and 1995/96 at Gwalior, Madhya Pradesh, India, Indian mustard cv. Pusa Bold was given 40: 20: 0, 80: 40: 5 or 120: 60: 10 kg NPZn/ha and 0, 30, 60 or 90 kg S/ha. Yields and yield component values, oil and protein contents, and net returns increased with increasing fertilizer rates.

Singh et al. (1999) reported that application of 45 kgS/ha increased the oil content, oil yield, protein sinigrin/glucosinolate content, and iodine value of oil by a margin of 5.57, 30.77, 8.63, 13.19 and 4.17% respectively compared to unfertilized controls.

Ganeshamurthy and Saha (1999) measured the sulphur status of soils is dependent more on agro-ecological conditions in which the soil occurs than other properties of the soils.

Gowrisankar and Shukla (1999) observed that the combined effect of soil characteristics on S extraction by different extractants, stepwise multiple regression analysis was carried out. Based on this study the suitability of the extractants for mustard crops in Inceptisol of Delhi is as follows: 0.15% $CaCl_2$ > Water soluble S > 0.001M HCl > $Ca(H_2PO_4)_2$ –500ppm >1% NaCl > NH_4OAc + HOAc > NaOAc + HOAc > KH_2PO_4–500ppm P > heat soluble S.

Gupta et al. (1999) conducted twenty surface and subsurface soils (Inceptisols and Entisols) sampled in the title region of India. The organic-S, sulphate S, non-sulphate S, water soluble-S and adsorbed S constituted 67.22, 5.76, 27.00, 9.68 and 9.83% of total S. All the forms of sulphur, except non-sulphate S, decreased with depth. Out of the six extractants use of ammonium acetate was the most suitable for S extraction. Approximately 30% of the mustard (*Brassica juncea*) plant samples were deficient in sulphur.

Jaggi and Sharma (1999) conducted a pot experiment to study S responses at three levels (0, 30 and 60mg/kg) in *Brassica juncea* using 13 soils from Kangra district of Himanchal Pradesh, India. With 30 and 60 mg S/kg application, a consistent significant increase in dry matter yield, S uptake and a decrease in flowering period (advanced maturity) was observed in all soils. An advancement in maturity by 2 to 4, and 4 to 11 days was recorded following S application of 30 and 60 mg/kg, respectively.

Jaggi and Dixit (1999) have collected thirteen soil samples from different vegetable growing areas of Himanchal Pradesh and analysed them and used to fill pots (8 kg soil/pot) into which onion cv. Patna Red seedlings were planted. Sulphur was applied at 0, 15 or 30 ppm (0, 240 and 480 mg/pot, respectively) and constant rates of farmyard manure and NPK fertilizers were also applied. In terms to S application were observed. The most effective S rate varied depending on the particular soil sample.

Ram et al. (1999) conducted a screen house experiment on an

Ustipsamment soil of Haryana, India, to study the comparative response of eight rabi crops to sulphur application. The results showed the highest response in raya [*Brassica juncea*], an oilseed crop, followed by pulses. Among pulse crops, the highest increase in grain yield was observed in lentil followed by peas, fenugreek and gram. Similarly in rabi cereals barley, oats and wheat responded to S application in descending order. Sulphur concentration was greatest in raya grain and lowest in cereals.

Sakal et al. (1999) studied the effect of sulphur on yield, N, P, K and S nutrition of crops which was evaluated in a field experiment under rice-wheat system in a highly calcareous soil at Rajendra Agricultural University, Pusa farm for three consecutive years. The optimum level of S for rice and wheat application exhibited synergistic effect on N and antagonistic effect on P and K content in rice, and synergistic effect on N, P and K content in wheat. The optimum N:S ratio in grain and straw of rice was 10.34 and 4.51, and in wheat this ratio was 17.8 and 6.7, respectively. Protein content in rice and wheat grains was increased from 7.93 to 9.23 and 12.11 to 14.09 percent, respectively at their optimum S levels. Application of S enhanced the utilisation of N, P, K and S by rice and wheat crops. The average N,P,K and S removal by rice (grain + straw) was 87,12,113 and 13 kg ha^{-1}, and by wheat was 156, 14, 142 and 15 kg ha^{-1} respectively.

Singh et al. (1999) reported that amongst the oilseed and pulse crops, groundnut, mustard, niger, blackgram and lentil responded significantly to sulphur applied through gypsum, phosphogypsum and low grade pyrites, when these were grown in soils of upland physiography

(paleustalf). An increase of 5.7 q ha^{-1} in groundnut pod, 3.2 q ha^{-1} in mustard grain, 1.6 q ha^{-1} in niger grain, 2.4 q ha^{-1} in blackgram and 2.5 q ha^{-1} in lentil grain were obtained over control with applications of indigenous sources of S percent increase in yield due to S application varied from 13.6 to 42.5. Gypsum and phosphogypsum were found equally effective in acid soils to meet the S requirement of oilseeds and pulses for higher productivity. Pyrite was inferior with respect to yield of the first crop (mustard) and resulted in high residual response in second crop (blackgram) grown in a system in S deficient acid soil of Bihar plateau India.

Gupta and Sandhya (2000) conducted a pot experiment in a screen house, *B. juncea* cv. RH 30 was given 0, 10, 20, 30 or 60 µg S/g soil. Analysis of leaves 35 days after sowing showed that total lipid and non polar lipid contents were greatest with 10 or 20 µg S. Polar lipid content increased with increasing S rate. Percentage of linoleic and linolenic acids generally increased with S increasing rate, while those of palmitic and oleic acids decreased.

Singh et al. (2000) reported that the increase in seed yield and oil content due to 45 kg S/ha was recorded 23.9 and 5.6%, respectively, over no S application. Application of S up to 45 kg/ha also increased the mean net return and benefit: cost ratio.

Srinivasan et al. (2001) conducted a field trials at National Pulses Research Centre, Vamban, Tamil Nadu, India during the kharif and rabi seasons of 1995 and 1996 to evaluate the effect of different sources and levels of sulphur on the nodulation and protein content of blackgram.

Different sulphur sources viz., elemental sulphur (90% S) gypsum (15% S) and pyrite (20% S) were tried at 0, 10, 30 and 40 kg S/ha levels. Gypsum recorded the highest nodule number/plant (mean = 19.36), nodule dry weight (38.13) and nitrogenase activity (0, 522). Incerasing doses of sulphur increased all the above characters. Protein content was favourably altered due to gypsum application and higher doses of sulphur. Gypsum application produced significantly higher protein content which contributed to 9.8% and 8.7% increase over elemental sulphur and pyrite. Application of sulphur at 40 kg/ha produced the highest crude protein level during the Kharif (21.8%) and rabi (20.9%) seasons.

(b) Zinc In Soil And Plants:

Takkar et al. (1973) conducted field trials at Ludhiana with wheat, gram (Cicer arietinum), raya [*Brassica juncea*] potatoes, maize, bajra, rice, mash [Vigna mungo], groundnuts and guar [Cyamopsis tetragonolaba] given NPK, soil application of 50 kg $ZnSO_4$/ha increased yields of all crops. Under conditions of acute Zn deficiency, Zn applied to the soil was more effective in increasing yields than when applied as a foliar spray.

Gangwar and Singh (1991) observed that tissue concentration and plant uptake were increased by zinc whether applied as a seed coating (0.05-0.04% $ZnSO_4$) to the soil (5-20 kg Zn ha^{-1}) or as a foliar spray. The greatest Zn uptake and highest plant concentration was given by foliar spraying of $ZnSO_4$ at 15+45 days after emergence.

Prasad and Umar (1993) reported that Zn uptake increased with

rate of applied Zinc by rice cv. Sita, Pankaj and Jaishree. Residual effects of applied Zn were assessed in wheat cv. HUW 206, B.R. 346 and HUW 234. Zn uptake increased with residual Zn rate but there were no significant effect of zinc on grain and straw yield. Grain yield was highest ($2.81+tha^{-1}$) in HUW-234.

Sharma and Lal (1993) carried out a field experiment on 20 sites in Banswara district wheat cv. Sonalika was given 0, 10, 20, 30 or 40 kg. $ZnSO_4$ ha^{-1} to determine the critical limit of D.T.P.A. extractable Zn for wheat yield using the Cate and Nelson model the critical limit for deficiency was calculated as 0.6ppm for this area and soil type.

Sakal et al. (1993) observed that applied zinc increased grain yield and plant uptake of Zn at 2 sites i.e. Pusa and Dholi. At Pusa yield was highest (5.41 t ha^{-1}) with 25 kg $ZnSO_4$ ha^{-1} applied at transplanting (4.04 t ha^{-1}) but this was not significantly different from applying 25 kg ha^{-1} (yield 3.93 t ha^{-1}). Applying some of the Zn at tillering or panicle initiation or using $ZnSO_4$ foliar spray decreased rice yield compared with basal application.

Singh et al. (1993) conducted a field experiment on Zn deficient (0.56 ppm) sandy loam at Dholi, Bihar, 6 mustard [*Brassica juncea*] cultivars given 0, 5 or 10 kg Zn/ha as $ZnSO_4$, produced mean seed yields of 1.66, 1.76 and 1.92 t/ha, respectively. The interaction effect between Zn rate and cultivars was not significant. Seed yield ranged from 1.28 t in cv. RAUT-S-17 to 2.07 t in cv. BR 40. Zinc uptake in seeds and straw increased with increased in Zn rate. Oil yield was 735, 780 and 847 kg/ha with 0, 5 and 10 kg Zn/ha, respectively and was highest (919 kg) in BR 40.

Zhang (1993) studied on wheat cv. Ares was grown hydroponically with deficient or sufficient levels of zinc when both sets of plants were exposed to different Zn concentration (0.25, 1 or 4μ mol Zn/litre). Zn uptake rate per unit root D.W. increased with increasing concentration and was highest at all concentrations in the Zn deficient plants. Uptake was lower when Zn was supplied as Zn EDTA than as $ZnSO_4$ or Chelate of Zn phytosiderophores, due to different rates of loading to the root apoplast. Large pools of apopalasmic Zn were found in plants supplied with $ZnSO_4$, with much lower levels when Zn was supplied in chelated forms. Translocation of apoplasmic Zn to the shoot was greatest in Zn deficient plants.

Prasad et al. (1995) observed that the application of varying levels of zinc through zinc fulvate augmented dry matter yield, zinc uptake and percent zinc derived from fertiliser more than that from zinc sulphate. The relative amount of Zn in various fractions and relative distribution of applied ^{65}Zn in these fractions at 25 days of maize growth were in the order: (CBD) extractable Zn > organically bound Zn > complexed Zn > water soluble + extractable Zn > HCl soluble Zn. Different fractions of zinc increased with increasing levels of zinc. However, the distribution of applied ^{65}Zn in the treatment of zinc fulvate was greater than that of zinc sulphate. The path coefficient and step down regression analysis show that complexed Zn in the maize in calcareous soil treated with Zn-FA and HCl extractable Zn and CBD extractable Zn are important in soil treated with $ZnSO_4$.

Singhal and Rattan (1995) showed that zinc in water soluble and

exchangeable pools was virtually non existent major portion of the total Zn in the soil existed in the form viz. zinc specifically adsorbed on clays (Zn-AAC) organically bound (Zn-PYR) occluded by free oxides (Zn-Ox) and residual Zn (Zn-Res) fractions. The last fractions constitutes higher percentage of total zinc correlation data indicate that these fractions are in state of dynamic equilibrium and show a significant dependence of clay content organic carbon, C.E.C., $CaCO_3$ content and D.T.P.A. extractable Zn.

Chhibba et al. (1997) conducted a screen house experiment using 13 coarse textured soils with DTPA-extractable Zn ranging from 0.34 to 2.09 mg kg^{-1} to determine the critical value of Zn deficiency in soil and plants for predicting response of sorghum (Sorghum vulgare) to applied Zn dry matter yield of 60 day- old sorghum increased with the increase in available Zn status of the soil and a significant correlation ($r = 0.86$) was observed between these two. Available soil Zn showed a significant relation with Bray's percent yield ($r = 0.79$) as well as Zn concentration in the index leaf ($r = 0.98$). Both graphical and statistical methods of Cate and Nelson indicated 0.76 mg kg^{-1} and 8.8 mg g^{-1} as the critical values of Zn deficiency in soils and plants, respectively, below which sorghum may be expected to respond to Zn application.

Gupta et al. (1999) conducted a screen house experiment on a Zn deficient Ustipsamment soil of Haryana to study the comparative response of zinc application (0, 5 or 10 mg/kg soil) to nine rabi [winter] crops. Among the cereals, barley recorded the highest increase in grain yield (35%) with the application of 5mg Zn, followed by oats (31%) and wheat

(23%). Among the pulses crops, the highest increase in seed yield was recorded in lentil (125%) followed by methi (Trigonella sp.) (63%), gram (Cicer arietinum) (37%) and peas (22%). In oilseed crops, a response of 869% was recorded in linseed and 9% in raya [*Brassica juncea*] as compared to control. The Zn concentration of seeds/grains increased significantly over control in all the crops. The highest Zn concentration after Zn application was in oats. The highest increase in Zn concentration due to Zn application was recorded in peas followed by methi and barley. The lowest increase in Zn was recorded in raya, which had the highest seed Zn concentration of any crop in the control treatments.

Singhal and Rattan (1999) conducted pot culture experiments with soyabeans cv. PK-327 and mustard (*Brassica juncea* cv. Pusa Bold) as test crops on a zinc deficient (0.44 mg kg^{-1} DTPA-Zn) Typic Ustifluvent to evaluate the effect of sources and rates of zinc application on dry matter yield and zinc concentration. Zinc sources ($ZnSO_4$, Zn-EDTA, ZnO and $ZnCO_3$) were used at 0-10 mg Zn kg^{-1} soil. Seed yield was increased most by $ZnSO_4$, followed in decreasing order by Zn-EDTA, ZnO and $ZnCO_3$. Zn content in seed and shoot tissues increased with increasing Zn application rate, and was generally highest from Zn-EDTA followed by $ZnSO_4$ ZnO and $ZnCO_3$. Application of Zn increased the amount of available Zn in soil after harvest, with the lowest increase given by $ZnSO_4$, while the Zn source giving the greatest increase depended on extractant used.

Mandal et al. (2000) reported in a rice based cropping system soils are often subjected to different moisture regimes which may influence

desorption of absorbed Zn and thus limit Zn availability to crops. Laboratory and greenhouse experiments were conducted to study the effect of moisture regimes with or without organic matter addition on changes in desorption of adsorbed Zn in soils and its utilization by rice and maize plants. Three different moisture regimes: Flooded-dried, alternate wetting and drying and preflooding, with (50 g kg^{-1}) and without (0 g kg^{-1}) added organic matter were imposed in two Alfisols and two Inceptisols of West Bengal, India. Percent desorption of adsorbed Zn was significantly higher under flooded-dried (61.4%), alternate wetting and drying (67.1%) and preflooding (47.4%) moisture treatments than in the control (43.4%). Organic matter application enhanced desorption under flooded-dried and alternate wetting and drying but decreased it under preflooding. The variation in Zn desorption among soils and moisture treatments is the result of changes in soil pH, Fe-oxides, bonding energy constants, and free energies for Zn adsorption. Greenhouse experiments showed that dry matter yield and uptake and utilization of Zn for maize were higher under flooded-dried condition. For rice, yield and Zn accumulation were higher under preflooding treatments compared to the control in which the soils were not subjected to these pre-plant moisture treatments. Soil-zinc data and plant response were in close agreement, except in Inceptisols for rice under preflooding with added organic matter treatment. Results indicated a more efficient use of Zn fertilizer where maize followed rice, and where rice was grown after preflooding the soils.

Dube et al. (2001) reported that Pigeonpea when raised in pot-culture on an adequately fertilized loamy sand Gangetic upland semi-arid alluvial soil (Ustifluvent) of Putti village. Bulandshahar district in western

Uttar Pradesh showed positive responses to graded (1 to 25 mg kg^{-1} soil) Zn amendment. The increase in height, branching, production of pods and harvest index of pigeon pea was highest at 5mg kg^{-1} Zn added soil which raised DTPA extractable soil Zn and in middle leaves the concentration of Zn was 42.2 mg kg^{-1} (d 67). Critical values helpful in predicting 50 percent crop responses to Zn amendment were 0.52 mg kg^{-1} DTPA soil Zn and 25 mg Zn kg^{-1} leaf Zn for top yield. The threshold of deficiency values were 0.70 mg kg^{-1} in middle leaves indicated marked toxicity of Zn for top yield. The corresponding values representing threshold of toxicity were 3.0 mg kg^{-1} DTPA extractable Zn and 36.8 mg kg^{-1} Zn in middle leaves. These values will be helpful in predicting Zn status of soils as well as for crop plants growing on them.

Chitdeshwari and Krishnasamy (2001) carried out a greenhouse experiment to evaluate the residual effect of applied Zn and Zn-enriched organic manures on the micronutrient concentration in green gram cv. Co_5. The treatment structure composed of 5 levels of zinc (0, 1.25, 2.50, 3.75 and 5 mg Zn/kg) and 4 manurial combinations [Farm Yard Manure (FYM)], FYM+Green Leaf Manure (GLM), composted coir pitch (CCP) and (CCP+GLM) were applied at 12.5 t/ha as raw manures and 1.0 t/ha as composted manures. The zinc levels differed significantly in increasing the zinc availability and its concentration in green gram leaves. The increasing levels of zinc increased the DTPA-Zn in soil and its concentration in the plant. A two-fold increase in zinc content was observed in green gram after the application of 5.0 mg Zn/kg. The application of 5.0 mg Zn/kg enriched CCP+GLM recorded the highest mean Zn values (3-10 mg/kg in soil and 11.5 mg/kg in leaves). As the

levels of Zn increased, the availability of Fe and Mn declined. The increasing levels of Zn increased the Cu content in the leaves. In general, the ZnE organic manures applied at 1.0 t/ha significantly influenced the micronutrient availability than the application of recommended level of organic manures (912.5 t/ha).

(c) Sulphur And Zinc Relationship In Soil And Plants:

Sharma et al. (1990) conducted a greenhouse experiment on mustard with application of zinc and sulphur alone or in combination got increased the dry weights of plant roots and shoot. Zinc and sulphur uptake and cation exchange capacity of roots at flowering stage also got increased. Zinc and sulphur, alone or in combination, increased the stover and seed yield of mustard. The mean values of Zn and S nutrient flux between rosette and flowering stage were obtained to the extent of 2.1 and 162.1 $\mu g\ m^{-1}\ d^{-1}$, respectively.

Singh et al. (1997) conducted a field experiment at Kumarganj during summer of 1995 to study the effect of sulphur (0, 15, 30 and 45 kg/ha) and zinc (0, 5, 10 and 15 kg/ha) levels on summer green gram [Vigna radiata] cv. Narendra Mung-1. Application of 30 kg S and 5 Kg Zn/ha was optimum for plant height, branch number, functional leaves, dry matter accumulation, dry weight of nodules/plant, seed protein yield, and S and Zn uptake.

Shekhargouda et al. (1997) conducted a field experiment in Karnataka, safflower cv. Annigeri was given 0-40 kg S and 0-20 kg Zn/ha. The highest seed yields of 1669 kg/ha were given by 20 kg S+20

kg Zn/ha, 19.5% higher than the control plots.

Tripathi et al. (1997) conducted a field trial in winter 1990-92 at Kanpur, Uttar Pradesh and C. arietinum cv. Aurodhi was given 0-60 kg S as elemental sulphur and 0-7.5 kg Zn/ha as zinc chloride seed yield increased upto 40 kg S and 5 kg Zn/ha. High S and Zn application slightly decreased the yield.

Raghuwanshi et al. (1997) conducted a field trial at Indore in 1991-93, 25 or 50 kg S/ha as gypsum and 5 or 10 kg Zn/ha as $ZnCl_2$ or $ZnSO_4$ were applied in the rainy season every year or in alternate years. Soyabeans cv. JS 72-44 were grown in the rainy season and were followed by wheat. Application of 25 and 50 kg S/ha increased soyabean yield by 0.32 and 0.63 t/ha respectively. Soyabeans responded more to zinc application as $ZnSO_4$ than $ZnCl_2$. There was a residual effect of Zn on the following wheat crop, but S did not affect wheat yield significantly. Soyabean yield was highest when both S and Zn were applied at the higher rates each year.

Khandagave et al. (1997) observed in a field trial at Dharwad, Karnataka in Kharif [mansoon] 1990/91, cotton cv. Abadhita was given all combinations of 0, 20 and 40kg S and 0, 25 or 50kg $ZnSO_4$/ha. Seed cotton yield was not significantly affected by S, but Zn response was 1401, 1598 and 1522 kg/ha with 0, 25 and 50kg $ZnSO_4$, respectively.

Khurana et al. (1998) conducted field experiments in Punjab on a Fatehpur loamy sand (Typic Ustochrepts) to study the effect of application of 0-40 kg S and 0-11 kg Zn/ha on *Brassica juncea* cv. RLM-619 and its residual effect on a subsequent maize crop. S and Zn

applications increased *B. juncea* seed yield. The highest seed yield of 1.09 t/ha was obtained with 20 kg S+11.0 kg Zn, which was 45.3% higher than the control yield. The oil content of *Brassica juncea* seed was increased by 2.0% by the combined application of S and Zn. A portion of the applied nutrients remained in the soil, significantly increased the grain yield and the uptake of S and Zn in the subsequent maize crop.

Mandal and Halder (1998) conducted a pot experiment rice cv. BR11 was given all combinations of 0, 4, 8 or 12 kg Zn and 0, 5, 10 or 20 kg S/ha. Addition of 8 kg Zn+20 kg S/ha gave the best performance in growth and yield of the crop.

Meena and Singh (1998) conducted a pot experiment on a sandy Aridisol, a sandy clay loam Inceptisol and a clayey vertisol during the rabi season of 1995-96 raising onion as the test crop. The crop was grown to maturity. Dry weights were recorded for tops and bulbs separately. The results showed that S and Zn treatments significantly enhanced the dry weight of onion tops and bulbs. Higher level of 30 mg S kg^{-1} caused an antagonistic effect. A sulphur dose of 20mg S kg^{-1} on S-deficient soils and 10 mg S with 5 mg Zn kg^{-1} for low S soils was appropriate for better onion yields. Total S uptake by the onion crop on all three soils was enhanced significantly. The Aridisal was the most responsive to sulphur followed by the Inceptisol.

Sontakey et al. (1999) conducted a field experiment to study the response of groundnut to applications of sulphur and zinc to the soil. Pod yield was significantly increased by the application of sulphur and zinc. Groundnut genotype ICGS-44 showed the highest yield (2742 kg/ha)

followed by ICGS-11 (2631 kg/ha).

Buri et al. (2000) reported that a total of 172 soil samples from 85 locations within river flood plains and 201 samples from 78 locations within inland valley swamps in the title area were collected and analysed to determine their sulphur (sulphate-S) and micronutrients (Zn, Fe, Mn, Cu, Ni) supplying capacities. The soils were deficient in sulphate-S and available Zn. Mean top soil (0-15) cm sulphate-S levels were 3.41 mg/kg for river flood plains and 4.88 mg/kg for inland valley swamps. Even though mean topsoil available Zn levels were 1.23 and 1.56 mg/kg for river flood plains and inland valley swamps, respectively, over 66% of West Africa lowlands had available Zn below the critical soil level of 0.83 mg/kg necessary for rice cultivation.

Kumar et al. (2000) conducted field experiments on silty clay loam soil (Aeric Haplustalf pH 6.7) to study the effect of Zn (0, 10 and 20 kg/ha) and S (0, 30 and 60 kg/ha) application on their availability in soil in relation to yield and nutrition of onion cv. N-53. The results showed that the amount of DTPA-extractable Zn and 0.15% $CaCl_2$ extractable SO_4 –S in soil increased due to application of Zn as Zn-EDTA and S as the element, respectively. However, the magnitude of increase for both Zn and S was the highest in combined applications (Zn 20 S 60), exhibiting a synergistic relationship. In plants, separate application also recorded a significant increase in leaves, bulbs and roots, whereas combined application (Zn 10 S 60) significantly decreased their concentration in all plant parts, indicating an antagonistic relationship. The yield of onions was highest (18.04 t/ha) with the Zn at 10 kg/ha treatment. In combined

treatments the best yield (16.44 t/ha) was seen with the Zn_{20} S_{30} treatment.

Kumar et al. (2000) conducted a 2 years field experiment on a silty clay loam (Haplustalf) soil (pH 6.7) in rabi season of 1994-95 and 1995-96 to study the correlation coefficient matrix multiple regression and path analysis of onion (cv. N-53) as influenced by different levels of Zn as Zn-EDTA (0, 10 and 20 kg/ha) and S (0, 30 and 60 kg/ha) arranged in randomized block design with 3 replications. Eight week old seedlings were planted in first week of November and harvested in last week of March. The experiment was conducted under irrigated conditions. The results revealed that the yield of onion was positively correlated with plant height, number of leaves per plant, fresh weight of leaves per plant, number of roots per plant, total soluble solid content and total sugar content of onion bulbs. Path analysis showed that neck thickness had the highest direct positive effect on bulb yield, followed by bulb Zn content, whereas moisture content of bulbs and soil Zn content at 90 days after transplanting had a negative effect on onion yield. Multiple regression equations were formulated and are tabulated.

(d) Sulphur And Zinc Relationship With Other Nutrients:

Poletschny and Kick (1973) conducted a pot experiment with high rates of wet sludge which led to excess wetting of the soil, leading to anaerobic condition and thus to a marked growth reduction. After disappearance of the water, all 3 species responded very well to the high rates of sludge. Utilization of N decreased with increased in rate of

sewage sludge. Uptake of Cu, Zn and Pb increased with increasing sewage, but did not reach toxic level.

Cakmak and Marschner (1990) studied the effect of varied Zn supply on the pH of the nutrient solution and uptake of cations and anions in cotton, sunflower and buckwheat plants grown under controlled environmental conditions in nutrient solutions with nitrate as source of nitrogen. The results indicate that probably as a consequence of the role of Zn in plasma membrane integrity and nitrogen metabolism, when Zn is deficient in dicotyledonous species net uptake of NO_3^- is particularly depressed which in turn results in an increase in cation-anion uptake ratio and a corresponding decrease in external pH. The ecological relevance of this rhizoshere acidification is discussed.

Singh et al. (1994) conducted a field trial in the rabi (winter) season of 1988-89 on saline-alkali soils, the yield of late sown mustard [*Brassica juncea*] increased up to 120 kg N and 60 kg S/ha.

Singh et al. (1997) conducted a screen house experiment barley cv. BG-75 was gorwn in loamy sand soil low in available S, P and Zn and was given 0-90 mg P, 0-60 mg S and 0-20mg Zn/kg soil. The concentration and Zn significantly decreased S concentration in barley. Uptake of S increased up to 60 mg P and 5 mg Zn/kg soil. Application of S significantly increased the concentration and uptake of Zn up to 40 mg S/kg soil, however application of 60mg S/kg soil significantly decreased Zn concentration and uptake. P application had an antagonistic effect on Zn concentration, however uptake of Zn was increased upto 60 mg P/kg soil. The interaction effects of P×Zn, P×S and S×Zn were significant in

concentration and uptake of S and Zn.

Singh et al. (1997) conducted a screen house experiment, barley cv. BG-75 was grown on loamy sand (Typic Ustochrept) deficient in available P, S and Zn and given 0, 30, 60 or 90mg P kg^{-1} soil, 0, 20, 40 or 60mg S, and 0, 5 or 20mg Zn. The application of P, S and Zn significantly increased the dry matter yield of barley up to 60, 40 and 5mg kg^{-1} soil application, respectively. P×S, P×Zn and S×Zn interactions were significant for dry matter yield. The application of P and S significantly increased P concentration in barley, however, the application of Zn significantly decreased the P concentration at all rates. The application of P significantly increased its uptake at each rate. The application of S up to 40 mg kg^{-1} soil and Zn upto 5mg kg^{-1} soil also significantly increased the uptake of P. However, higher rates of S and Zn decreased P uptake.

Trivedi et al. (1997) conducted a field experiment carried out on sandy loam soil at Gwalior, Madhya Pradesh, during the rainy seasons (Kharif) of 1990 and 1991. Increasing levels of N, P_2O_5 and S significantly increased the seed and stover yields. Increases in mean seed yield over controls were 217, 273 and 109 kg/ha with 30kg N, 60kg P_2O_5 and 60kg S/ha, respectively. The application of N with S significantly enhanced the yield. Increasing levels of N, P_2O_5 and S significantly increased the total uptake of N, P and S. The maximum net return (Rs. 3893/ha) and BCR (2.01) was obtained with N 30 P60 S60.

Chowdhury et al. (1998) conducted a field study which was carried out at the Regional Agricultural Research Station, Hathazari Chittagong during the rabi seasons of 1989/90 and 1990/91 to determine

the response of cowpeas cv. Hathazari local to different fertilizer treatments. Fertilizer treatment significantly affected plant height, number of branches/plant, number of pods/plant, number of seeds/pod and 1000-seed weight as well as seed yield. Nitrogen and phosphorus were more effective in increasing the yield compared to other elements. Potassium and sulphur increased cowpea yield significantly up to 30 and 20 kg/ha respectively, while Zn had little effect. The highest yield (Pooled data) of 1327 kg/ha (211% increase over control) was obtained with N_{20} P_{60} K_{30} S_{20} Zn_5 kg/ha treatment. Higher N rate enhanced vegetative growth, but failed to increase seed yield.

Jaggi (1998) conducted a field experiment during the winter (rabi) seasons of 1990-91 and 1991-92 to study the individual and interactive effects of different rates of S and P fertilizers on Indian mustard cv. Varuna. Seed yield was increased by S application at 60 kg/ha. S applications of 30, 60 and 90 kg/ha increased seed yield by 121, 157 and 176%, respectively, compared with No. S. Similar increases in seed yield with P_2O_5 rates of 30 and 60 kg/ha were 36 and 82% respectively. A significant positive interaction between the 2 nutrients in increasing seed and straw yields was observed, giving the highest seed (21.5 quintals/ha), and straw (69.0 q) yields with combined applications of S and P_2O_5 at their maximum rates. An improvement in seed: straw ratio accompanied by early crop maturity, as evident from the flower count, was affected by both the nutrients at their sole application rates of 30 kg/ha. Highest seed straw ratio (0.33) was evident from the treatment combinations of 60 kg S and 60 kg P_2O_5/ha.

Patel et al. (1998) studied the distribution of Fe, Mn, Cu, Zn and S in soils of the Kathlal, Rakhiyal, Dehgram, Silaj and Ranodar series (Inceptisols) and Oganaj series (Entisols) which are representative of soils in the district. Data were tabulated on the content of these elements at 4 or 5 depths in each soil type and on particle size distribution, pH, electrical conductivity, organic carbon and available P_2O_5 and K_2O contents. The soils were generally deficient in Fe, Zn and S.

Purakayastha and Nad (1998) studied, *Brassica juncea* cv. Pusa Bold and Wheat (Triticum aestivum) cv. HD-2307 grown in a typic ustochrept soil in pots were given equivalent to 0-90 kg S and 0-60kg Mg ha^{-1} in combinations with 1ppm Mo. Application of all nutrients increased seed/grain yields. The highest *B. juncea* yield was given by combined application of all nutrients, while wheat grain yield was highest with 60kg Mg alone. The response to S was higher in *B. juncea* than in wheat. Uptake of N, P and K in *B. juncea* and that of N only in wheat were substantially higher with the increase in S level. Quantitatively, *B. juncea* required more P, S, Mg and Ca while N and K were taken up in higher amounts by wheat.

Sreemannarayana et al. (1998) conducted a field experiment in 1995 in Andhra Pradesh, sunflowers cv. Morden were given 0-100Kg N and 0-60kg S/ha. N and S applications increased the uptake of N, P, K, Ca, Fe, Zn, Cu and Mn. S application decreased Mg uptake, whereas Mg uptake increased with increasing N rate. DM yield was highest (3.48 t/ha) with 100kg N+60kg S.

Attia (1999) conducted a field experiment in summer 1995 and

1996 on a Typic Torrifluvent soil at the experimental farm of the Faculty of Agriculture, Assiut University Egypt, sorghum cv. Al-Droado (dwarf variety) was given 90 or 120 kg N/feddan as filter mud cake (2.25%N), ammonium nitrate (33.5% N) or an equal mixture of the two, and 0, 250 or 500 kg S/feddan. S and filter mud cake decreased soil pH and increased soil organic matter content and available P. Straw and grain yields increased with increasing N and S rates, and were greatest with filter mud cake+ammonium nitrate. Leaf N, Fe and Mn contents increased with increasing N rate while leaf P and Zn contents decreased. Leaf P, Fe, Mn and Zn contents increased with increasing S rate, but leaf N and K contents did not change [1 feddan = 0.42 ha.].

Varavipour et al. (1999) conducted a greenhouse pot experiment, wheat cv. HDF 2329 and soyabeans cv. PK327 were grown in rotation on a Typic Ustochrept and were each given 0, 13.4, 26.8 or 40.2 mg P/kg, 0, 4.46, 8.92 or 13.38mg S/kg and 0 or 12.7mg Zn/kg. Uptake of N, P and S was significantly increased by applied P and S in both wheat and soyabeans. P at 26.8 and 40.2mg/kg and all S rates increased the seed yield of soyabeans, but Zn had no effect. Application of S at 8.92 and 13.38mg/kg increased the oil content in soyabean seeds. The most effective combinations were 40.2 mg P + 13.38 mg S/kg for grain yield of wheat, 26.8 mg P + 13.38 mg S/kg for seed yield of soyabeans and 8.92 mg S/kg for oil content of soyabean seeds. The optimum rates for overall yield and quality of both crops were 26.8 mg P+8.92 mg S+12.7 mg Zn/kg soil.

Pandey et al. (2000) observed that wide variability in the

availability of phosphorus and sulphur in different soil associations of district Kanpur in Central Uttar Pradesh. Contents of available P ranged from 7.7 to 55.4 kg ha^{-1}. Abut 49, 50 and 1 percent soil samples showed, respectively, low, medium and high range of phosphorus availability correlation studies revealed that availability of phosphorus in all the soil associations, in general, was significantly and positively influenced by organic matter and finer soil particles (clay). Available S contents varied from 5.8 to 53.8 mg kg^{-1} in different soil associations. It was observed that about 41 and 59 percent soil samples showed deficiency and sufficiency, respectively in S availability. In correlation studies S availability in all the soil associations was found significantly and positively affected by organic matter, CEC and finer soil particles (clay).

Raut et al. (2000) conducted a field experiment on mustard on a farm in Akola, India, during the rabi season of 1996-97 to study the effect of irrigation and sulphur on the concentration, uptake and availability of sulphur nitrogen and phosphorus.

(e) Effect Of Sulphur And Zinc On Quality Of Crops:

Tripathi et al. (1997) conducted a field experiment on a Typic Ustochrept in Uttar Pradesh, India, Chickpea (Cicer arietinum) responded significantly to the application of S and Zn. The magnitude of response was more marked with S than with Zn addition. However, these had an antagonistic effect. Sulphur and Zn had a significant positive effect on protein and S-containing amino acids. Sulphur-containing amino acids increased significantly with increase in S dose.

Babhulkar et al. (2000) studied the individual and interactive effects of sulphur (0, 30, 45, 60 kg S ha^{-1}) and zinc (0, 15, 30, 45kg Zn ha^{-1}) along with 50kg each of N and P_2O_5 ha^{-1} on safflower for yield, quality and nutrient uptake in a swell-shrink soil. Application of 45kg S ha^{-1} recorded significantly high dry matter and seed yield (2.61 t ha^{-1}) and seed nutrient content. Application of zinc recorded significant response up to 15 gk Zn ha^{-1} for seed yield (2.37 t ha^{-1}). However, significantly high straw yield (7.62 t ha^{-1}) and nutrient content in seed and dry matter were recorded with the application of 30 kg Zn ha^{-1}. Increase in levels of S and Zn increased significantly the oil and protein content in seed. The interaction of sulphur and zinc was significant and the highest seed (29.34 q ha^{-1}) and straw yield (94.23 q ha^{-1}) were obtained with the combined application of 45 kg S and 15 kg Zn ha^{-1}.

Hunashikatti et al. (2000) conducted a field experiment during 1998-99 to study the individual and interaction effect of sulphur and molybdenum on yield and quality parameters of cabbage. Application of sulphur alone @ 25 kg ha^{-1} and molybdenum alone @ 1 kg ha^{-1} produced maximum yield of cabbage (58.46 t ha^{-1}) and protein content (6.83%) in head. Whereas the maximum ascorbic acid (54.38mg 100 g^{-1}) obtained with 50kg S ha^{-1} and 2 kg Mo ha^{-1}. Combined application of 25 kg S and 1 kg Mo ha^{-1} was still more beneficial to produce maximum yield and better quality of cabbage (63.19 t ha^{-1}) with fair amount of protein (7.25%) and ascorbic acid (49.12mg 100 g^{-1}).

Kumar et al. (2000) conducted a field experiment at Kalyani on a silty clay loam (Haplustalf) of pH 6.7, onion cv. N-53 was given 0, 10 or 20kg Zn/ha and 0, 30 or 60kg S/ha. Bulb yield was highest (18.4 t/ha)

when 10kg /ha Zn alone was applied. Data are also tabulated on TSS, ascorbic acid, reducing sugar moisture, pyruvic acid and anthocyanin contents.

Prasad (2000) conducted a field experiment at the Research Farm of the Indian Agricultural Research Institute, New Delhi during 1997-98 and 1998-99 to study the influence of N, P and S on cotton (Gossypium, hirsutum) and their residual effect on succeeding wheat (Triticum aestivum). It was observed that application of 100kg N/ha gave highest seed-cotton yield over control. Application of phosphorus and sulphur significantly influenced only fibre strength, N and P applied to cotton showed significant residual effect on grain yield and yield attributing characters of wheat. Transplanted wheat gave more grain yield (14.0 q/ha) than direct seeded wheat. In case wheat sowing is delayed due to aberrant weather, wheat variety HD 23285 can be transplanted even in last week of December or first week of January for getting higher grain yield of wheat.

Raut et al. (2000) have found in a field trial that maximum protein percentage with 60 kg S/ha, whilst maximum oil percentage was recorded with 40 kg/ha. Protein and oil yields both increased with increasing S applied upto 60 kg/ha.

Majumdar and Pingoliya (2001) conducted a field experiments in Rajasthan, India to determine the effects of different sulphur (S) sources (Pyite, element S and gypsum) and levels (20, 40 and 60 kg/ha) for the best qualitative production of Indian mustard cv. T-59 on loamy sand soil. The highest seed N content (3.17%) was recorded upon gypsum treatment, although it was not significantly higher than that of pyrite and elemental S. The highest P and S contents in the seed (0.791 and 303%, respectively and stover (0.115 and 151% respectively) and the highest uptake of N, P

and S in the seed (46.70, 11.43 and 4.45 kg/ha, respectively) and stover (19.27, 4.33 and 5.69 kg/ha) were recorded upon treatment with gypsum. The highest N, P and S contents in the seed (3.233, 0.795 and 0.297%) and in stover (0.528, 0.117 and 0.152%) and the highest uptake of N, P and S in the seed (46.95, 11.62 and 4.50 kg/ha) and stover (19.12, 4.47 and 5.40 kg/ha) were recorded upon treatment with 60kg S/ha. The highest increase in protein and oil content in seed was recorded upon treatment with gypsum (20.14 and 38.82% respectively) with 60 kg S/ha (20.21 and 39.02%, respectively).

Dwivedi et al. (2002) conducted a field experiment on Typic Ustochrept, the individual effects of S (0, 15, 30 and 45 kg S ha^{-1}) and Zn (0, 2.5, 5 and 10 kg Zn ha^{-1}) were studied on maize for yield, quality and nutrient uptake by maize (Zea mays L). Application of S up to 30 kg ha^{-1} enhanced the average grain yield of maize by 22 percent over control. The application of Zn up to 5 kg ha^{-1} increased the maize grain yield by 19 percent over control. On fitting the average grain yield data of two years into quadratic equation, the optimum dose of S for maize was found to be 34.3kg ha^{-1} for the maximum grain yield of 29.7 q ha^{-1}. Similarly, the optimum dose for zinc was found to be 7.1kg ha^{-1} giving maximum grain yield of 29.8 q ha^{-1}. Similar trend in yield response of stover was also recorded. Total S uptake progressively increased from 6.13 to 9.19 kg ha^{-1} with the increase of S levels. The uptake of Zn also increased with the levels of Zn. The uptake of N, P and K increased upto 30 kg S and 5 kg Zn ha^{-1} level. Protein content increased significantly with the increase of S and Zn over control. Tryptophan and lysine contents were found to increase with increased levels of Zn, while adverse effect was noted with increased levels of S.

CHAPTER-III

MATERIALS AND METHODS

MATERIALS AND METHODS

With the objective to study the effect of sulphur and zinc on yield and nutrient uptake by mustard and chickpea, the present investigation was conducted in the field and laboratory. The nature and characteristics of the materials used and the techniques and methods followed during the course of investigation are briefly describes as follows:-

3.1 Experimental Site:

The site for experiment was Agricultural Farm of the Sheila Dhar Institute of Soil Science, which is located near Mumfordganj at Allahabad. The Agricultural Farm being irrigated by tube well water supplied by the Jal Sansthan, Allahabad. The field experiments were conducted during the year-2000 to 2002.

3.2 Climate:

The climate of Allahabad is known for its cold winter and intolerable summers. The average rainfall about 82.0cms and average temperature varied from 32.4 to 36.0°C with mean humidity of about 64 percent.

3.3 Soil Characteristics:

Mostly soil of Allahabad district is old alluvial soil. The Sheila Dhar Institute Farm has also alluvial soil belonging to order-Inceptisol,

sub-order-Ochrepts, Greatgroup-Eurochrepts, Subgroup-Typic Eurochrepts, Family-Coarse silty, mixed thermic, series-Natchez and the texture of soil is sandy clay loam. Soil is generally deficient in nitrogen, organic carbon and zinc moderate in phosphorus and sufficient in potassium.

3.4 Soil of Experimental Field:

Surface soil samples (0-15cm) were initially drawn from randomly selected parts of the field before sowing and fertilizer application. A composite sample was obtained by mixing them thoroughly. The quantity of composite sample was reduced to about one kg.

The soil samples were analysed for some important characteristics and are presented in table 3.1.

3.5 Collection of Soil Samples:

Bulk soil samples (0-15cm) were collected with the help of on auger from various parts of the plot for the experimental purpose. The soil samples were also collected at before sowing and after harvest of the crop.

3.6 Preparation of Soil Samples for Analysis:

The representative samples about 1.0kg of each experimental plots were brought to laboratory and air dried in shade. Wooden hammer was used for crushing and ponding the clods. After thorough mixing they were ground and then passed through 2mm sieve. The unsieved particles were again and again crushed thoroughly mixed and finally passed through the same sieve. The soil samples thus prepared were kept in the same polythene bags and staked in the soil racks for analysis.

Table 3.1: *Some important soil characteristics*:

Soil Characteristics	Mustard field soil 2000-01	Chickpea field soil 2001-02
Coarse sand (%)	0.36	0.34
Fine sand (%)	58.65	60.71
Silt (%)	21.25	19.20
Clay (%)	18.40	18.36
pH	7.60	7.80
E.C. (dSm^{-1})	0.30	0.35
Cation Exchange Capacity (mol kg^{-1}	13.10	12.62
Organic carbon (%)	0.75	0.69
Total nitrogen (%)	0.13	0.11
Available nitrogen (ppm)	31.00	29.50
Total P_2O_5 (ppm)	197.00	194.00
Available P_2O_5 (ppm)	16.30	14.50
Total K (ppm)	470.00	450.00
Available K (ppm)	63.50	62.00
Total S (ppm)	230.00	192.00
Available S (ppm)	9.50	9.00
Total Zn (ppm)	82.00	77.00
Ammonium citrate extractable Zn (ppm)	0.65	0.62

3.7 Collection of Plant Samples:

Plant samples were taken at harvesting from all the replications. The samples were oven dried, ground and subjected to chemical analysis.

3.8 Plant Height:

The plant height of above ground parts of 5 plants from 3 spots in each plot was measured at maturity and averaged to express per plant.

3.9 Grain and Straw Yield:

At maturity each plot was harvested and thrashed separately and grain yield was recorded in kg per plot and expressed finally in qha^{-1} after adjusting 11 percent moisture in grain. The straw yield was obtained by substracting grain yield from the total biological yield of each plot and expressed finally in qha^{-1}.

3.10 Methods Employed for Soil and Plant Analysis:

(a) Soil Analysis

1. **Mechanical Analysis**: Mechanical Analysis was done by Hydrometer method as given by Chopra and Kanwar (1999).

$$\text{Silt - percent of silt + clay in the soil} = \frac{(w_2 - w_1)1000 \times 100}{25 \times 20}$$

$$\text{Clay - percent clay} = \frac{(w_2 - w_1)1000 \times 100}{25 \times 20}$$

Sand - percentage of sand $= \frac{(w_2 - w_1)100}{20}$

2. **pH** (1:2.5 Soil water suspension) : pH value was measured by the pH meter Elico. Model L-110, Electronic Industrial Co. Pvt. Ltd. Hyderabad.

3. **EC:** Electrical conductivity of 1411.8×10^{-3} i.e. 1.41 dSm^{-1} at 25°C of saturation extract was determined with the help conductivity meter as outlined by Singh et al. (1999).

4. **CEC:** Cation Exchange Capacity ($Cmol(+)kg^{-1}$) cation exchange was determined (Ammonium acetate extractable) by the method described by Chopra & Kanwar (1999).

5. **Organic Carbon:** Determined by Walkley and Black method as given by Singh et al. (1999).

6. **Total Nitrogen:** Total nitrogen was estimated by Kjeldahl Method as described by Chopra & Kanwar (1999).

7. **Available Nitrogen:** Available nitrogen was estimated by Alkaline Potassium Permanganate method as described by Tandon (1993).

8. **Total Phosphorus:** Total P_2O_5 was estimated by precipitating it through Ammonium molybdate solution as described by Chopra & Kanwer (1999).

9. **Available Phosphorus:** It was determined calorimetrically after extracting with Olsen's reagent 0.5m $NaHCO_3$. Singh et al. (1999).

10. **Total Potassium:** Potassium in the extract is estimated by the

cobaltinitrit method as described by Chopra and Kanwer (1999).

11. **Available Potassium:** It was determined by ammonium acetate method (Hanway and Heidel-1952) using flame photometer as given by Singh et al. (1999).

12. **Total Sulphur in soil:** The organic sulphur of soil is oxidised to sulphate by sodium peroxide followed by fusion with sodium carbonate to break down the soil minerals. The sulphate is determined by Precipitation as barium sulphate as determined by Chopra and Kanwer (1999).

13. **Available Sulphur in soil:** Available sulphur was determined turbidimetrically by barium sulphate application using colorimeter as described by Chesnin and Yien (1951) mentioned in Analytical Agricultural Chemistry, Chopra & Kanwer (1999).

Reagent: Sodium acetate-acetic-acid buffer: Dissolved 100 g of sodium acetate in about 500 ml of water and added 30 ml of 99.5 percent acetic acid and made up to 1 litre.

Gum acacia solution: 0.25 percent.

Barium chloride: Ground crystals of $BaCl_2.\ 2H_2O$ in an agate mortar to pass a 30-mesh sieve.

Standard Sulphate Solution: Dissolved 0.5 370 g A.R. $CaSO_4.2H_2O$ in sodium acetate-acetic acid buffer and diluted to 1 litre with more of sodium acetate- acetic acid buffer again diluted 10 ml of this solution to 1 litre and this contains 1ppm of sulphur.

Procedure: Weighed 20 g of air dried soil into a 250 ml flask. Added 100 ml of sodium acetate-buffer and shook for 30 minutes. Filtered through a Whatman No. 42 filter paper and transferred 10 to 20 ml of the extract to a 25ml volumetric flask. Added 1 g of the 30 to 60ml mesh barium chloride crystals and shook for 1 minute. Added 1 ml of the gum acacia solution, made up the volume and shook for 1 minute. Took turbidity readings in a period of 5 - 30 min using a photoelectric colorimeter with a blue filter on a spectrophotometer. Standard curve was prepared on spectrophotometer taking 1, 2, 3, 4 ,5, 8 and 10 ml of the standard sulphate solution by developing turbidity as given above.

(3 ppm or less of the extractable sulphur indicates sulphur deficiency)

14. **Total Zinc content of soil:** 1g of soil was taken in a beaker and 5ml of conc. HNO_3 and 5ml $HClO_4$. The solution was heated upto dryness on the hot plate. Solution was then filtered in 50ml volumetric flask and volume was computed with the help of distilled water. 10 ml Amo. Citrate Solution (25%) was added and pH was adjusted to 7.0 with addition of 5 N NH_4OH using litmus paper. Extraction of Zn was done with 0.005% dithiozone solution and estimation was colorimetrically carried out as mentioned in 'CHEMISTRY of the SOIL' by Fireman E. Bear (1965).

15. **Available Zinc in soil:** Zinc was determined colorimetrically by the dithizone method, which is extracted with ammonium citrate given by Chopra & Kanwar (1999).

Reagent:

1. Zinc free distilled water.
2. Hydrochloric acid (0.02 N and 1 N).
3. Ammonium hydroxide (0.02 N).
4. Carbon tetrachloride.
5. Thymole blue as indicator.
6. Ammonium citrate.
7. Dithizone.

Carbamate: Prepared 0.2 % solution of carbamate by dissolved 0.2 g of di-phenyldi-thio-carbamate in 100 ml of zinc free distilled water. Kept the solution in a brown bottle.

Dithizone solution in CCl4: Taken in separatory funnel of 4 litre capacity and then added 0.2 g of di-phenyl dithiocarbamate . Again 1 litre of CCl_4 in this funnel was added with constant stirring for about 15 minutes. To this solution then added 2 litres of zinc free 0.02 N NH_4OH and shook the mixture to transfer the dithizone to the aqueous phase. Discarded the CCl_4 layer having green colour and rinsed the aqueous phase several times with CCl_4. Then added 500 ml of CCl_4 and 50 ml of zinc free 1 N HCl. Shook the mixture to transfer the dithizone to the CCl_4 layer and then dilute this solution to 2 litres and siored in a glass stoppered pyrex bottle in a refrigerator.

Ammonium citrate: Ammonium citrate (pH 8.5) Dissolved 90 g ammonium citrate in distilled water and made the volume to 1 litre. Added NH_4 OH to bring the pH to 8.5. Removed the zinc impurities present by extraction with dithizone in CCl_4 in a separatory funnel until

dithizone in CCl_4 no longer changed the colour. After this, extracted the solution with CCl_4 until the citrate solution was free from dithizone colour.

Standard Zinc Solution: Prepared zinc solution containing 100 μg per ml by dissolved 0.1 g of pure zinc in 50 ml of 0.02 N H_2SO_4 and made the volume to one litre with water. This solution was used to draw a standard curve by taking colorimetric readings with 0, 1, 2, 4, 6, 8 and 10 ml of the standard zinc solution and developing colour in the same manner.

Procedure: Took solution containing about 5 to 20 μg of zinc in 30 to 40 ml of 0.02 N HCl in a separatory funnel of 125ml capacity. Now added 50 ml of ammonium citrate buffer and 3 ml of carbamate. Adjusted the pH of the solution to 8.5 with the addition of NH_4OH or HCl (using thymole blue indicator). To the above solution added10 ml of dithizone reagent. After shaking the mixture thoroughly, transferred the CCl_4 layer to another separators funnel. Added 25 ml of 0.01 N NH_4OH to the CCl_4 phase, and shook well to extract the excess dithizone into the aqueous phase.

Now mixed 5 ml aliquot of the organic phase with 25 ml of CCl_4 and transferred the solution to a colorimeter tube and measure the optical density on a spectrophotometer at 535nm. The amount of zinc was determined present by reference to a standard curve prepared earlier by taking standard zinc solution.

(b) Plant Analysis:

1. **Preparation of Plant Samples:** Plant samples taken at harvesting stage of crop growth was first air dried under shade, and then kept in an oven at 60°C for 48 hours to become free from moisture. The oven dried samples were ground passed through 0.5mm sieve and stored in the sample bottles.

2. **Nitrogen:** It was determined by Kjeldahl's method as given by Singh et al. (1999).

3. **Phosphorus:** It was determined by Molybdenum blue calorimetric method, Singh et al. (1999).

4. **Potassium:** It was determined by Ammonium acetate method Hanway and Heidel-1952 using Flame photometer as given by Singh et al. (1999).

5. **Sulphur:** It was determined by barium sulphate precipitation method as given by Chopra and Kanwar (1999).

6. **Zinc:** Zinc was determined colorimetrically by the dithizone method, which is extracted with ammonium citrate given by Chopra & Kanwar (1999).

Zinc uptake:

Zn concentration in plant X plant weight

(i) in (g ha^{-1}) $= \dfrac{\text{Content (ppm)} \times \text{yield (g ha}^{-1}\text{)}}{10,\ 00000}$

or $\quad = \dfrac{\text{Content (ppm)} \times \text{yield (g ha}^{-1})\times 100\times 1000}{10,\ 00000}$

(ii) in (Kg ha^{-1}) $= \dfrac{\text{Content (\%)} \times \text{yield (Kg)}}{100}$

7. **Protein:** Weighed about 1-2g of the material and determined nitrogen in it by Kjeldahl method as described by Chopra and Kanwar (1999).

Crude protein = wt. of nitrogen × 6.25

Percentage of crude protein = Crud Protein × $\dfrac{100}{\text{wt. of sample}}$

8. **Oil:** Oil content of seed crop mustard was determined by "Soxlet Method" using petroleum ether for extraction as described by Rawate and Das (1968).

3.11 Statistical analysis:

The data were statistically analysed by standard method mentioned in Agricultural Statistics Singh & Verma.

(i) SE (m) ± $\dfrac{\sqrt{V_E}}{r}$

(ii) $CD_{(P=0.05)}$ = SE (m) ± × $\sqrt{2}$ × $t_{(0.05)}$

EXPERIMENTAL NO. 1

Distribution of available sulphur and zinc in different blocks of district Allahabad and Fatehpur.

In the month of June, after the crops were harvested, all the samples of soils were collected from each Block of Allahabad and Fatehpur district. These samples of soils were collected in polythene and brought to laboratory Sheila Dhar Institute of Soil Science for soil chemical analysis for available S and Zn.

EXPERIMENT NO. 2

A field experiment was carried out at the Sheila Dhar Experimental Farm to find out the sulphur and zinc in soil-plants relationship on growth and yield parameters. Sulphur and zinc content of plants at different growth intervals and at harvesting were determined. Effect of these nutrients was also studied on response of the soil nutrient status. The experiment was conducted during rabi season of 2000-01 and mustard variety T-9 was grown as test crop in both the years. Initial soil samples were collected from experimental farm and analysed for their physico chemical characteristics using standard methods. Soil was found to have following composition as given in table 3.1.

(a) Experimental Details:

The field experiment was laid out in a Factorial experiment using R.B.D. with 12 treatment combinations having three replications. The

total number of plots was 36. The treatment of sulphur and zinc were alloted as follows:

(i) Leveils of sulphur applied: 4 (0,20,40 and 60kg S ha^{-1})

(ii) Leveils of Zn applied : 3 (0,5 and 10 kg Zn ha^{-1})

(iii) Total treatment combinations = S level × Zn level = 12

(iv) Name of Design – R.B.D. (Factorial)

(v) Replication : 3

(vi) Total number of treatment : 12×3 = 36

(vii) Size of plot : 1×1 Sqm.

(viii) Crop – mustard (Brassica compestiris)

(ix) Date of Sowing : In 2000: 29.09.2000

(x) Date of Harvesting : In 2001: 07.01.2001

The soil was incorporated with sulphur and zinc at above mention doses in the form of elemental sulphur (95%S) and ZnO (78%Zn) respectively. The sulphur was applied @ 0, 20, 40 and 60 kg ha^{-1} as basal dose according to the treatments and zinc was applied @ 0, 5 and 10 kg ha^{-1} as basal dose according to the treatments.

The soil was mixed with the help of stick and made suitable for sowing of crop. The plots were irrigated with tap water whenever it was required.

Mustard crop was harvested on 7 January 2001 during 2000-01 crop season and stem, podhusk and grain yield were recorded soil samples were collected just after harvesting of crop from all the plots. Dried, processed and stored for the analysis as per method.

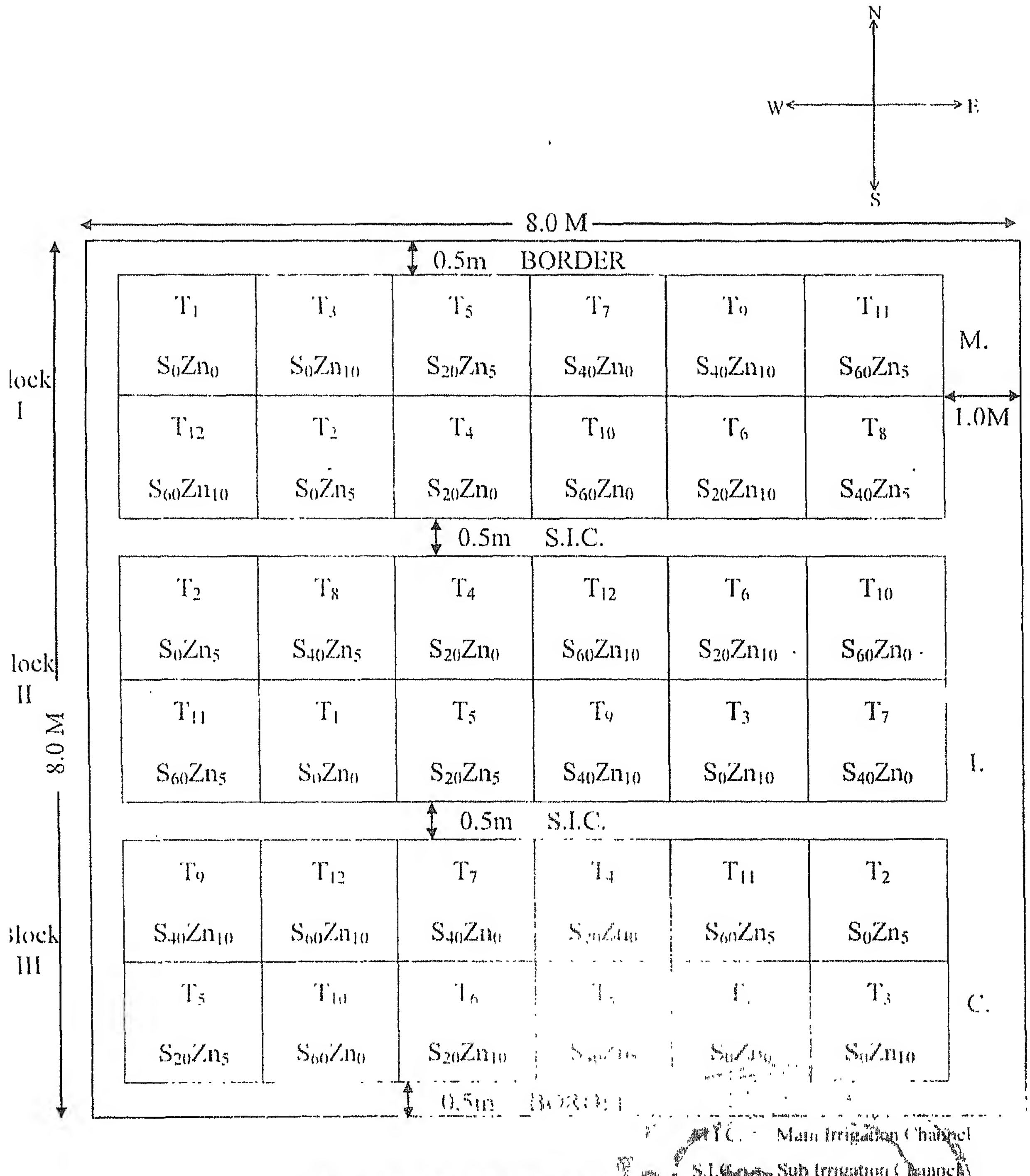

Fig.: LAY-OUR PLAN

(b) Details of treatments combinations:

Sr. No.	Particulars	Treatment combinations
1.	0 Kg S + 0 Kg Zn ha^{-1}	S_0 Zn_0
2.	0 Kg S + 5 Kg Zn ha^{-1}	S_0 Zn_5
3.	0 Kg S + 10 Kg Zn ha^{-1}	S_0 Zn_{10}
4.	20 Kg S + 0 Kg Zn ha^{-1}	S_{20} Zn_0
5.	20 Kg S + 5 Kg Zn ha^{-1}	S_{20} Zn_5
6.	20 Kg S + 10 Kg Zn ha^{-1}	S_{20} Zn_{10}
7.	40 Kg S + 0 Kg Zn ha^{-1}	S_{40} Zn_0
8.	40 Kg S + 5 Kg Zn ha^{-1}	S_{40} Zn_5
9.	40 Kg S + 10 Kg Zn ha^{-1}	S_{40} Zn_{10}
10.	60 Kg S + 0 Kg Zn ha^{-1}	S_{60} Zn_0
11.	60 Kg S + 5 Kg Zn ha^{-1}	S_{60} Zn_5
12.	60 Kg S + 10 Kg Zn ha^{-1}	S_{60} Zn_{10}

Basal dose NPK - 90kg, 50 kg, and 40kg

EXPERIMENT NO. 3

The experiment was conducted in rabi season during 2001-02. The chickpea (Cicer arietinum L.) cv. Pusa-261 was sown as test crop in the same plots in which mustard was grown during 2000-01. The soil was incorporated with NPK fertilizers @ 20Kg-N, 60Kg-P, and 30Kg-K ha^{-1}

CHAPTER-IV

RESULTS AND DISCUSSION

RESULTS & DISCUSSION

The results of the present investigation and discussion thereon have been presented in this section under the following experiments: –

1. Available S and Zn status in soils of Allahabad and Fatehpur Region.

2. Effect of S and Zn application on plant height, number of branches, yield, content and uptake of S and Zn and Oil content of Mustard crop.

3. Effect of S and Zn application on plant height, number of branches, yield, content and uptake of N, P, K, S and Zn ; and protein content of Chickpea.

EXPERIMENT NO.1

A field survey of different blocks in Allahabad and Fatehpur district was carried out to study the "Available S and Zn Status of soils of different Blocks of district Allahabad and Fatehpur region". Since very little information regarding the distribution of both S and Zn in the soils of this region was available, the present survey was carried out with the objectives: (i) to collect the information regarding the status of S and Zn and (ii) to locals the S and Zn deficient areas in this region.

4.1 Available S and Zn Status in Soils of Allahabad and Fatehpur Region:

The sulphur and zinc status of soil is dependent more on agro-ecological conditions in which the soil occurs than other properties of soils. It is hence more meaningful to present and discuss the S and Zn status of soils of different blocks of Allahabad and Fatehpur region.

(a) Available Sulphur Status of Soils:

The available S content of soils of district Allahabad and Fatehpur ranged from 2.4 to 75.4 and 2.4 to 81.2 ppm with mean value of 14.25 and 13.61 ppm, respectively, as shown in the table 4(1.1). The highest mean (18.12 ppm) of available S was recorded at Mau-Aima block in Allahabad whereas, the lowest mean (12.39 ppm) of available S was observed in Bahadurpur block in Fatehpur.

The soil in this region are Inceptisol. These soils are sandy clay loam in texture, neutral to slightly alkaline in reaction (pH 7.0-7.8) and low to medium in organic matter and available S. Rice and wheat are the dominant crop and plantation and mostly vegetable crops are grown. Significant response of applied S can be obtained in this region. The total information is based on the analysis of 340 soil samples. Out of 340 soil samples, 200 soil samples were taken from Allahabad block and the remaining 140 soil samples were taken from Fatehpur block. Tiwari (2000) and Swarnkar & Verma (1978) have provided similar reports.

Table 4(1.1)

Available S and Zn Status of soils of different blocks of district Allahabad and Fatehpur

Blocks	No. of Samples analysed	Avall. S ppm Range	Avall.-S ppm Mean	Avall.-S ppm Range	Avall-Zn ppm Mean
Allahabad District					
Bahadurpur	10	3.4-52.4	12.39	0.4-5.5	0.74
Chail	10	3.9-64.8	15.70	0.4-7.3	0.72
Dhanupur	10	2.8-57.5	13.62	0.5-6.8	0.76
Holagarh	10	4.2-62.2	13.09	0.4-7.2	0.77
Handia	10	5.1-65.2	13.23	0.4-6.5	0.69
Jarsa	10	2.7-46.8	12.91	0.6-5.0	0.75
Kada	10	2.5-48.4	14.02	0.5-7.3	0.78
Kadupur	10	2.4-63.5	15.58	0.4-7.6	0.76
Kanaili	10	3.2-60.9	17.35	0.5-6.3	0.73
Koraon	10	4.4-75.4	17.52	0.4-5.3	0.75
Manda	10	2.5-64.8	14.97	0.4-7.0	0.77
Mahuadih	10	2.8-68.4	13.27	0.5-6.7	0.70
Manjhanpur	10	4.1-70.5	14.26	0.4-6.6	0.78
Mau Aima	10	2.9-71.2	18.12	0.5-5.6	0.76
Partappur	10	2.6-72.0	16.35	0.5-6.3	0.78
Phulpur	10	3.4-60.4	13.50	0.4-6.7	0.73
Sarsawan	10	3.8-48.6	16.43	0.6-6.1	0.75
Sarswatipur	10	5.6-52.8	17.68	0.5-7.2	0.74
Shankergarh	10	2.8-63.4	13.98	0.4-5.3	0.68
Sirathu	10	2.6-55.5	14.83	0.5-6.5	0.71
District over all	200	2.4-75.4	14.25	0.4-7.6	0.74

Blocks	No. of Samples analysed	Avall. S ppm Range	Avall.-S ppm Mean	Avall.-S ppm Range	Avall- Zn ppm Mean
Fatehpur District					
Amouli	10	2.9-78.5	15.57	0.4-6.3	0.79
Asothr	10	3.5-70.0	16.25	0.5-5.6	0.70
Bhandra	10	2.6-74.5	14.51	0.4-5.8	0.72
Bhithama	10	3.8-72.3	10.42	0.6-7.5	0.81
Bijaipur	10	2.7-74.5	14.73	0.7-5.3	0.75
Bindki	10	2.5-73.1	13.68	0.4-6.5	0.73
Bohuwa	10	2.7-76.2	11.82	0.7-6.2	0.86
Deomai	10	2.4-75.3	12.72	0.5-6.8	0.70
Dhata	10	2.5-70.7	14.46	0.4-7.0	0.74
Fatehpur	10	3.4-78.2	12.08	0.6-6.5	0.78
Haswa	10	3.5-72.5	14.23	0.4-5.3	0.67
Hathgaon	10	2.6-80.7	13.05	0.5-6.1	0.71
Khaga	10	2.8-80.5	13.31	0.6-7.2	0.79
Malwau	10	2.7-81.2	13.80	0.5-6.8	0.74
District over all	140	2.4-81.2	13.61	0.4-7.5	0.74

(B) Zinc Status of Soils:

The available Zn content of soils of district Allahabad and Fatehpur ranged from 0.4 to 7.6ppm and 0.4 to 7.5ppm respectively with mean value of 0.74 ppm as presented in the table 4.11. The maximum mean (0.86ppm) was recorded at Bahuwa block of Fatehpur, whereas the

minimum (0.67ppm) was recorded at Haswa block in Fatehpur.

The soil of this region belongs to coarse silty and the texture of soil is sandy clay loam. Soil is generally deficient in N, organic carbon and Zn, moderate in phosphorus and sufficient in potassium. Significant response of added Zn as Zinc chelates can be obtained in this region. The upland soils of this region had 0.67 to 0.76 ppm (mean) as compared with 0.76 to 0.86 ppm (mean) under low land condition. Datta and Ram (1993) have provided similar reports.

EXPERIMENT NO.2

A field experiment was laid out with mustard variety T-9 in 2000-2001 to study the effect of varying levels of S and Zn and their interaction in the following treatments with normal doses of nitrogen, phosphorus and potassium.

Table –4.2.1

T_1	$S_0\ Zn_0$	T_7	$S_{40}\ Zn_0$
T_2	$S_0\ Zn_5$	T_8	$S_{40}\ Zn_5$
T_3	$S_0\ Zn_{10}$	T_9	$S_{40}\ Zn_{10}$
T_4	$S_{20}\ Zn_0$	T_{10}	$S_{60}\ Zn_0$
T_5	$S_{20}\ Zn_5$	T_{11}	$S_{60}\ Zn_5$
T_6	$S_{20}\ Zn_{10}$	T_{12}	$S_{60}\ Zn_{10}$

Doses = S @ 0,20,40 and 60 kg ha^{-1} through elemental sulphur ($\dot{S}$)

Zn @ 0,5 and 10 kg ha^{-1} through zinc oxide (ZnO)

The NPK fertilizers were incorporated in the experimental plots in usual manner. Sulphur and Zinc through elemental sulphur ($\dot{S}$) and zinc oxide (ZnO) respectively were mixed in different combinations to study the growth parameters viz. grain, stem and pod husks yields and the nutrient content and uptake of S and Zn in mustard grain.

The results and findings obtained from the experimental plots have been recorded in Table –4.2.1 and discussed thoroughly are as follows:

4.2.1 Effect of S and Zn application on height of Mustard Crop:

(a) Plant Height (30 D.A.S.):

Data presented in Table-4.2.2 indicates that the plant height increased significantly with increasing levels of sulphur and zinc. Increasing levels of sulphur increased the plant height significantly over the control during 2000-2001.

The maximum height of plants was obtained with 60 kg S ha^{-1} application and the plant height increased by 38.13 percent at over the control plot.

Table 4.2.2: Effect of S and Zn application on mustard crop height 30 D.A.S.

(Expressed in Cm.)

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	24.83	27.80	29.80	34.30	29.18
Zn_5	26.56	29.20	33.06	35.76	31.14
Zn_{10}	27.53	30.26	36.70	38.56	33.26
Mean	26.30	29.08	33.18	36.20	

	SE (±)	C.D. (5%)
S	0.76	1.58
Zn	0.66	1.37
S×Zn	1.32	N.S.

Increasing levels of Zn increased the plant height significantly (Table-4.2.2).

The maximum height of plants viz. 27.53cm. (mean) was obtained at 10kg Zn ha^{-1} as against 24.83cm. in control respectively. The increase in plant height with 10kg Zn ha^{-1} was at par with that of 5kg Zn ha^{-1} level. Influence of sulphur and zinc interaction on plant height appeared non-significant. Data computed at 5% level of significance revealed that the application of S at 60 kg ha^{-1} alongwith 10 kg ha^{-1} of zinc was superior over the other treatments on height of plants. Maximum plant height was measured with 60 kg S ha^{-1}.

It may be due to more uptake of sulphur as stimulated by the application of zinc. Similar resutls have been reported by Swarnkar (1984), Singh and Rajput (1980), Rathore and Manohar (1989).

(b) Plant height (60 D.A.S.):

It is clear from the table 4.2.3 that the plant height of 60 D.A.S. significantly and positively affected by different doses of sulphur. The highest plant height of 136.90cm recorded at 60kg S and 10kg Zn level was computed 49.3% higher over the control set. Sulphur individually increased the plant height by 44.2% whereas zinc by 7.5% only.

Thus response of sulphur was observed at higher magnitude than zinc. It may be concluded that the experimental soil was deficient in sulphur content therefore application of 60 kg sulphur increased the plant height by 44.2%. Chaniara and Damor (1982) have reported similar effect of S in increasing the plant height.

Table 4.2.3

Effect of S and Zn application on mustard crop height 60 D.A.S.

(Expressed in Cm.)

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	91.7	113.0	130.4	132.2	116.8
Zn_5	97.3	115.0	130.4	135.6	119.5
Zn_{10}	98.6	117.2	133.7	136.9	121.6
Mean	95.8	115.0	131.5	134.9	

	SE (±)	**C.D. (5%)**
S	3.94	8.18
Zn	3.41	7.08
S×Zn	6.83	N.S.

(c) **Plant height (90 D.A.S.):**

It is obvious from the data given in the table 4.2.4 that the plant height linearly increased with increasing doses of sulphur and zinc upto 60 and 10kg ha^{-1} respectively. All the levels of S and Zn gave synergistic effect in relation to plant height of mustard.

Both treatments of sulphur and zinc were observed positively and highly significant, whereas, the interaction between S and Zn was found non-significant. The maximum plant height of 155cm was observed at 60kg S and 10Kg Zn level was computed 50.5% and 18.33% higher over the control set and the height of grand mean respectively. Pandey (1996) have also reported similar findings.

Table 4.2.4: Effect of S and Zn application on mustard crop height 90 D.A.S.

(Expressed in Cm.)

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	102.96	122.23	132.73	144.80	125.68
Zn_5	112.70	126.96	134.30	151.66	131.40
Zn_{10}	116.20	129.70	142.53	155.00	135.85
Mean	110.62	126.29	136.52	150.48	

	SE (±)	**C.D. (5%)**
S	1.19	2.47
Zn	1.03	2.14
S×Zn	2.06	N.S.

4.2.2 Effect of S and on number of branches (60 D.A.S.):

The data in the table 4.2.5 revealed that sulphur individually affected the number of primary and secondary branches positively and significantly. The highest number of primary branches was observed at 60 kg sulphur and 5 or 10kg zinc level which was computed 70% higher over the control set. Sulphur individually increased the number of primary branches by 66%. The response study showed non-significant effect of S×Zn interaction, whereas, the effect of sulphur individually was found highly significant.

:

Table 4.2.5: Effect of S and Zn on number of Primary branches of mustart crop at 60 D.A.S.

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	5.0	6.6	7.3	8.3	6.8
Zn_5	5.3	7.0	8.0	8.6	7.2
Zn_{10}	6.3	7.0	8.0	8.0	7.3
Mean	5.5	6.8	7.7	8.3	

	SE (±)	**C.D. (5%)**
S	0.28	0.60
Zn	0.25	0.52
S×Zn	0.50	N.S.

Table 4.2.6: Effect of S and Zn on number of secondary branches in mustard crop 60 D.A.S.

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	9.6	13.3	15.3	16.6	13.7
Zn_5	11.3	14.0	15.6	17.3	14.5
Zn_{10}	12.6	14.6	16.3	18.6	15.5
Mean	11.1	13.9	15.7	17.5	

	SE (±)	**C.D. (5%)**
S	0.36	0.74
Zn	0.31	0.64
S×Zn	0.62	N.S.

It is interesting to note that zinc was observed significant regarding the number of secondary branches at 60 D.A.S. of mustard. The maximum number of secondary branches was observed at 60 kg S and 10kg zinc level which was computed 94.7% higher over the control set, whereas sulphur individually increased by 76.8% over the control set. This increase in number of primary and secondary branches may be due to the increased availability of sulphur, causing accelerated photosynthetic rate and thus leading to more number of branches. Similar findings have been reported by Antil (1986).

4.2.3 Effect of S and Zn application on number of branches (At harvesting)

The data in the table 4.2.6 indicated that both sulphur and zinc significantly influenced the number of the primary and secondary branches at harvesting of the crop.

The highest number of primary branches (mean=10.1) and secondary branches (mean = 22.3) recorded at 60 Kg S and 10 Kg Zn level were computed 77.2 and 85.8% higher over the control set respectively. Sulphur individually increased the number of primary and secondary branches by 57.8 and 73.3% higher over the control set respectively.

Thus application of sulphur significantly increased the number of primary and secondary branches upto higher levels during both the stages. This increase in number of primary and secondary branches may be attributed to better nutritional environment for plant growth at active vegetative growth. Similar findings were also reported by Singh (1983).

Table 4.2.7: Effect of S and Zn on number of primary branches in mustard crop at harvesting.

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	5.6	7.3	7.6	9.0	7.3
Zn_5	6.0	7.6	8.3	9.6	7.8
Zn_{10}	6.6	8.0	8.6	10.3	8.3
Mean	6.0	7.6	8.1	9.6	

	SE (±)	C.D. (5%)
S	0.39	0.81
Zn	0.34	0.70
S × Zn	0.68	N.S.

Table 4.2.8: Effect of S and Zn on number of secondary branches in mustard crop at harvesting.

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	12.0	14.3	17.6	20.6	16.1
Zn_5	12.6	15.6	18.3	21.6	17.0
Zn_{10}	13.6	16.6	19.6	22.3	18.0
Mean	12.7	15.5	18.5	21.5	

	SE (±)	C.D. (5%)
S	0.44	0.91
Zn	0.38	0.79
S×Zn	0.76	N.S.

4.3.4 Effect of S and Zn application on grain yield:

The data in the table 4.2.8 revealed that sulphur and zinc significantly and positively influenced the grain yield of mustard. The interaction of S×Zn was also observed significant. The highest grain yield of 23.86 q ha^{-1} recorded at 60 kg S and 10 Kg Zn level was computed 75.9% higher over the control set. Sulphur individually increased the grain yield by 67%, whereas zinc by 24.4% over the control set. The combined application of 60 kg S and 10 Kg Zn gave 20.7% extra yield than their individual effects. Almost similar results have been reported by Singh et al. (2000), Singh et al. (1998) and Khurana et al. (1998).

Table 9: Effect of S and Zn application on grain yield of mustard crop.

(Expressed in q ha^{-1})

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	13.56	15.67	17.31	22.65	17.39
Zn_5	15.25	18.50	19.86	23.53	19.29
Zn_{10}	16.87	21.04	22.91	23.86	21.17
Mean	15.23	18.40	20.03	23.35	

	SE (±)	**C.D. (5%)**
S	0.42	0.87
Zn	0.36	0.75
S×Zn	0.72	1.50

The above findings indicated remarkable effect of sulphur in increasing the grain yield of mustard. Grain yield of mustard increased

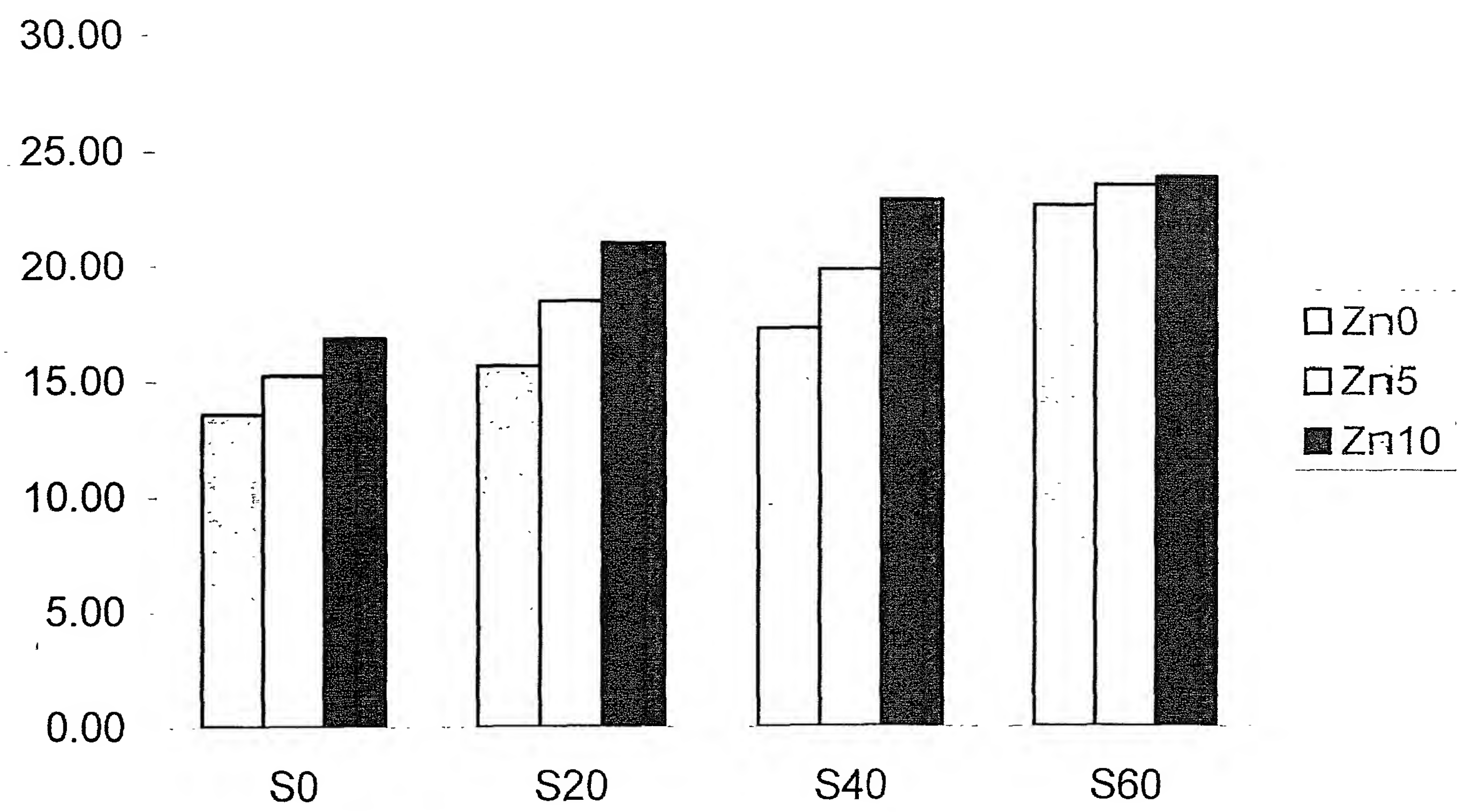

Figure: 4.2.1 Effect of S and Zn application on grain yield of Mustard Crop.

from 13.5 q ha^{-1} to 23.86 q ha^{-1} with increasing doses of sulphur upto 60 kg level and zinc upto 10 kg level. The mustard crop has been found more responsive to sulphur as compared to other crops.

4.2.5 Effect of S and Zn application on yield of stems and podhusk:

It is obvious from the table 4.2.9 & 4.2.10 that sulphur, zinc and their interaction significantly influenced the stem yield and podhusk yield during 2000-2001. The straw and pod husk yield was observed highest of 59.85 and 30.1 q ha^{-1} recorded at 40 kg S + 5Kg Zn and 60 kg S level respectively, which were computed 47 and 58.6% higher over the control set. Sulphur individually increased the stem and podhusk yield from 40.58 to 51.39 and 18.98 to 30.10 q ha^{-1} which were computed 26.3 and 58.6% higher over the control set. The effect of S and Zn stem yield was found synergistic at lower level of 40 kg S and5 kg Zn and then it was observed antagonistic at higher level. Zinc, increased the stem and pod husk yield by 11 and 2.5% respectively at 5 kg level and then decreased the stem by 1.5% and increased the podhusk by 1.4%, indicating indefinite trend in relation to their yields.

The combined effect of 40kg S and 5 kg Zn gave 23.9 and 13.4% extra yield of stem and pod husk than sum of their individual effects indicating significant effect of S×Zn interaction in the stem yield of mustard. Sarkar (2000), Singh (1995) and Singh (2001) have reported similar findings.

Table 4.2.10: Effect of S and Zn on application on stems yield of mustard crop.

(Expressed in q ha^{-1})

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	40.68	47.05	51.39	47.65	46.69
Zn_5	45.20	55.43	59.85	47.27	51.94
Zn_{10}	50.42	63.21	45.70	45.30	51.16
Mean	45.43	55.23	52.31	46.74	

	SE (±)	**C.D. (5%)**
S	0.52	1.09
Zn	0.45	0.94
S×Zn	0.91	N.S.

Table 4.2.11: Effect of S and Zn on pod husks yield of mustard crop.

(Expressed in q ha^{-1})

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	18.98	28.37	29.15	30.10	26.65
Zn_5	22.87	28.76	29.50	28.18	27.33
Zn_{10}	26.99	27.00	28.87	27.95	27.70
Mean	22.95	28.04	29.17	28.74	

	SE (±)	**C.D. (5%)**
S	0.40	0.84
Zn	0.35	0.73
S×Zn	0.70	N.S.

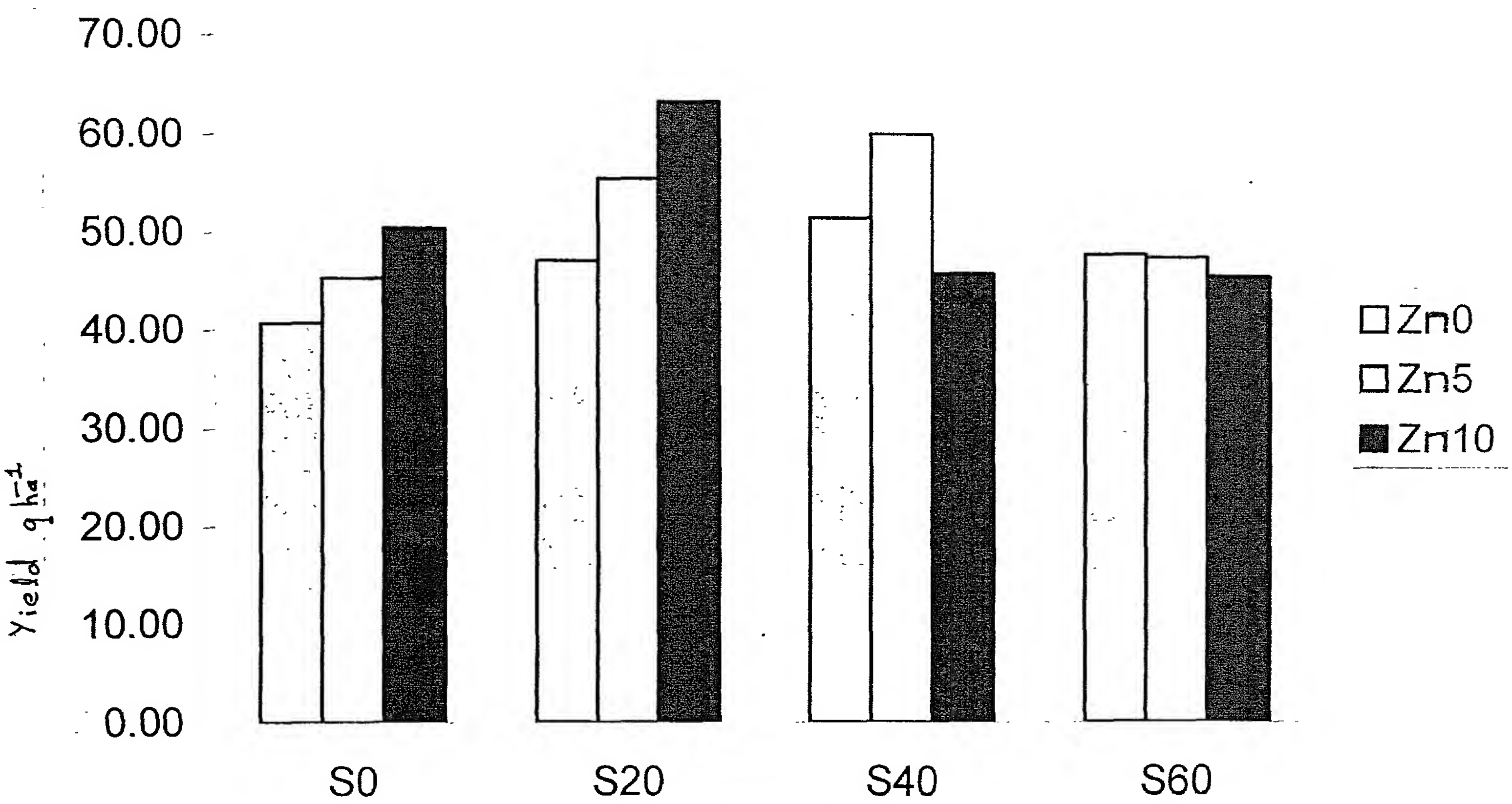

Figure: 4.2.2 Effect of S and Zn application on stem yield of Mustard Crop.

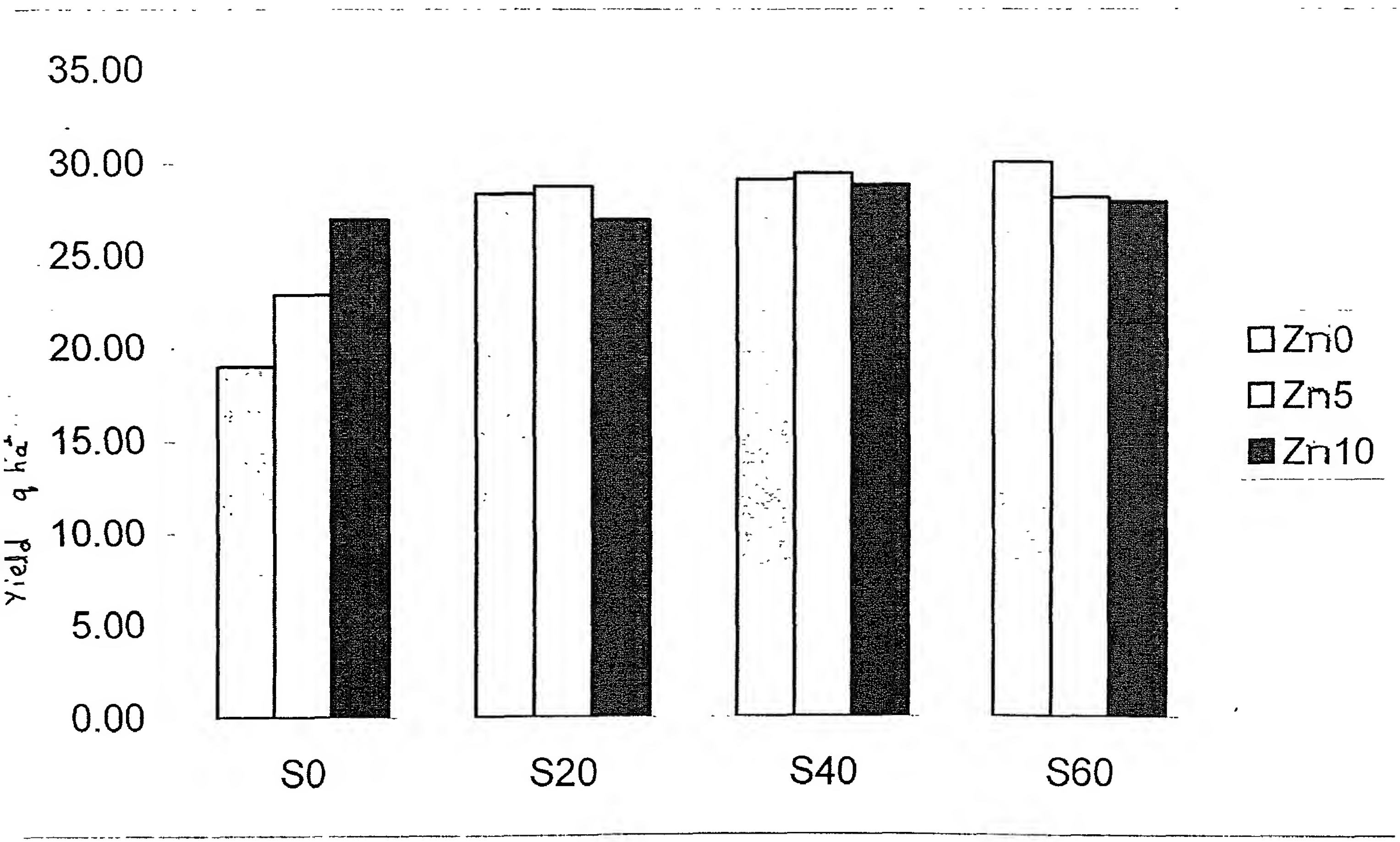

Figure: 4.2.3 Effect of S and Zn application on pod husks yield of Mustard Crop.

The above findings suggested that sulphur application is essential for high productivity of mustard crop. The application of 20 to 40kg S and 5kg Zn level improved the grain and stem yield. Therefore sulphur should be included in fertilizer recommendation for mustard crop.

4.2.6 Effect of S and Zn application on content and S-uptake in grain of mustard crop:

From table 4.2.11 to 4.2.12, it is revealed that S and Zn application at different levels significantly influenced the S content and thereby its uptake in mustard crop. The S content was found in the mustard grain to the extent of 0.64% in the control set where no application of S and Zn was carried out similarly the S uptake was calculated on the basis of grain yield comes to 8.78 kg ha^{-1}. The maximum S content (0.74%) was found in T_{12} treatment, which contained $S_{60}\times Zn_{10}$ application. S uptake in

Table 4.2.12: Effect of S and Zn application on S content in grains of mustard crop.

(Expressed in %)

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	0.64	0.68	0.70	0.73	0.69
Zn_5	0.66	0.69	0.71	0.74	0.70
Zn_{10}	0.67	0.69	0.72	0.74	0.71
Mean	0.66	0.69	0.71	0.74	

	SE (±)	C.D. (5%)
S	0.0025	0.005
Zn	0.0021	0.004
S×Zn	0.0043	0.009

Table 4.2.13: Effect of S and Zn application on S-Uptake by grains of mustard crop.

(Expressed in kg ha^{-1})

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	8.78	10.73	12.13	16.60	12.06
Zn_5	10.17	12.78	14.09	17.43	13.62
Zn_{10}	11.42	14.63	16.57	17.73	14.59
Mean	10.12	12.71	13.11	17.25	

	SE (±)	**C.D. (5%)**
S	0.31	0.64
Zn	0.27	0.56
S×Zn	0.54	1.12

mustard grains also got increased to the extent of 17.73 kg ha^{-1}. The increase of S content and its uptake may be due to higher availability of S by S×Zn interaction. The S content in grains of all the 3 treatments viz. T_{10}, T_{11} and T_{12} having 60 kg S ha^{-1} application were found to contain higher S that S_{40} and S_{20} treatment combinations. Sulphur individually increased the S-content by 90% whereas zinc by 30% in grain. The combined effect of S_{60}×Zn_{10} application gave 21.4% extra content of S than the sum of their individual effects in grain of the mustard crop.

The above findings indicated significant effect and synergistic relationship between S×Zn interaction in response to increasing the S content and S uptake in mustard crop.

Similar finding have been reported by Singh et al. (1999), Jaggi and Sharma (1999), Gupta and Sandhya (2000) and Majumdar and Pingoliya (2001).

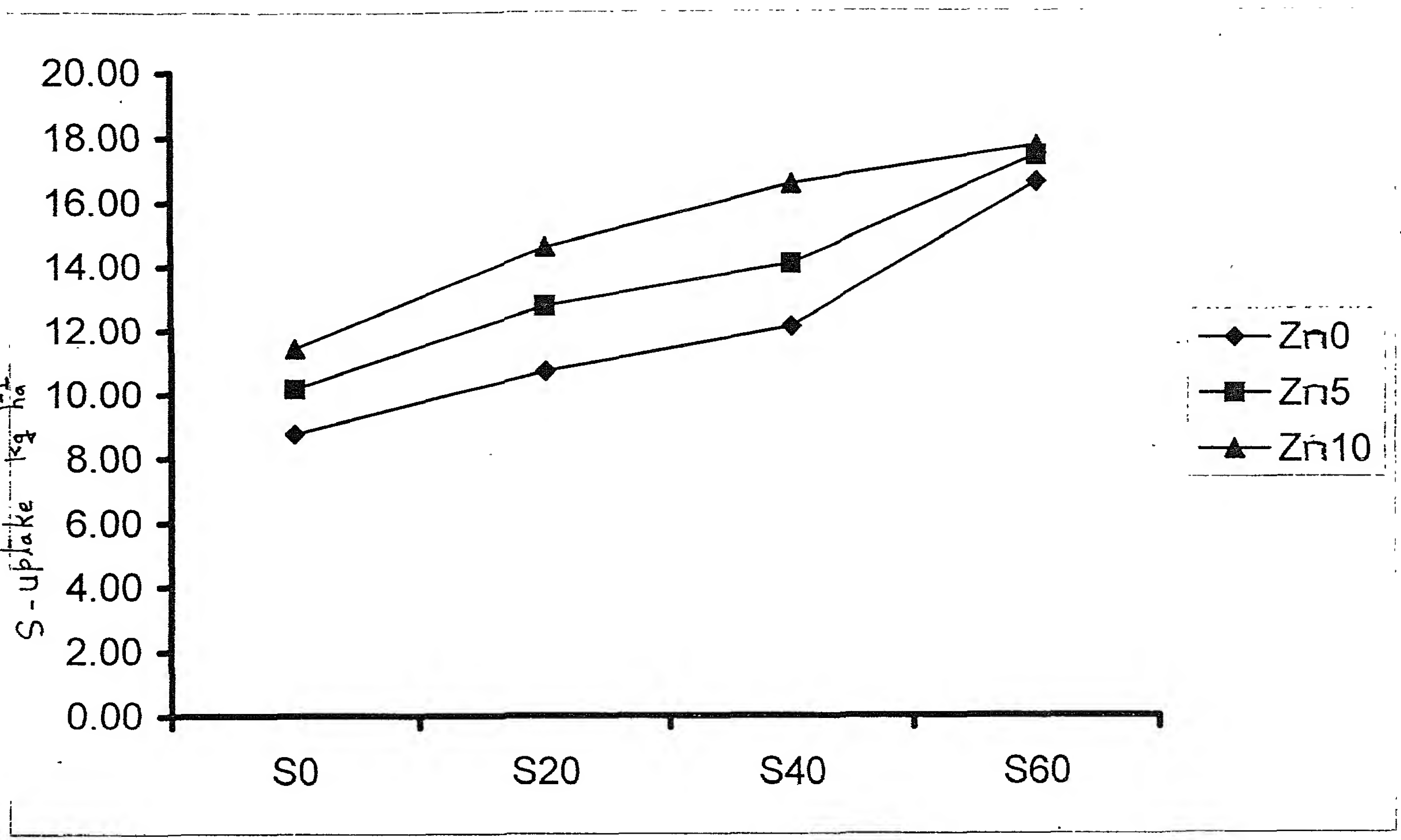

Figure: 4.2.4 Effect of S and Zn application on S-uptake by grains of mustard crop.

4.2.7 Effect of S and Zn application on Zn-content and Zn-Uptake in grain of mustard crop:

The table-visualizes that S and Zn application at various levels significantly influenced the Zn-content and thereby its uptake in grain of mustard. The Zn content was observed to the extent of 16.39ppm in the control set. Similarly the Zn uptake was calculated 22.26g ha^{-1}. The maximum Zn content (51.23ppm) was found in T_9 treatment, which contained $S_{40} \times Zn_{10}$ application. S-uptake in mustard grain also got increased to the extent of 117.97 g ha^{-1}. The increase of S-content and its uptake may be due to higher availability of Zn by S×Zn interaction. The Zn content in grain of all the treatments having 10 kg Zn ha^{-1} application was found to contain higher zinc than Zn_5 and Zn_0 treatment

Table 4.2.14: Effect of S and Zn application on Zn content in grains of mustard crop.

(Expressed in ppm)

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	16.39	24.75	28.52	38.28	26.99
Zn_5	34.24	45.90	42.32	46.69	42.29
Zn_{10}	48.52	50.23	51.23	49.57	49.89
Mean	33.05	40.29	40.69	44.85	

	SE (±)	C.D. (5%)
S	4.30	8.91
Zn	3.72	7.72
S×Zn	7.44	N.S.

Table 4.2.15: Effect of S and Zn application on Zn-Uptake in grains of mustard crop.

(Expressed in g ha^{-1})

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	22.25	38.83	49.51	86.65	49.31
Zn_5	52.03	84.52	83.70	110.11	82.59
Zn_{10}	81.70	106.75	117.73	117.96	105.04
Mean	51.99	76.70	83.65	104.91	

	SE (±)	**C.D. (5%)**
S	9.01	18.69
Zn	7.80	16.19
S×Zn	15.61	N.S.

combinations. Zinc and sulphur application individually increased the Zn-content by 196 and 133.5% in grain, respectively. The combined effect of $S_{40} \times Zn_{10}$ application provided 33% extra Zn-uptake in grain than sum of their individual effects.

From the above findings, it may be concluded that the optimum level of sulphur (40 kg ha^{-1}) with both the levels of zinc (5 and 10 kg ha^{-1}) may be recommended for higher content and uptake of zinc in mustard crop. Similar findings have been reported by Takkar et al. (1973), Singh et al. (1993), Gupta et al. (1999), Singhal and Rattan (1999) and Chitdeshwari and Krishnaswamy (2001).

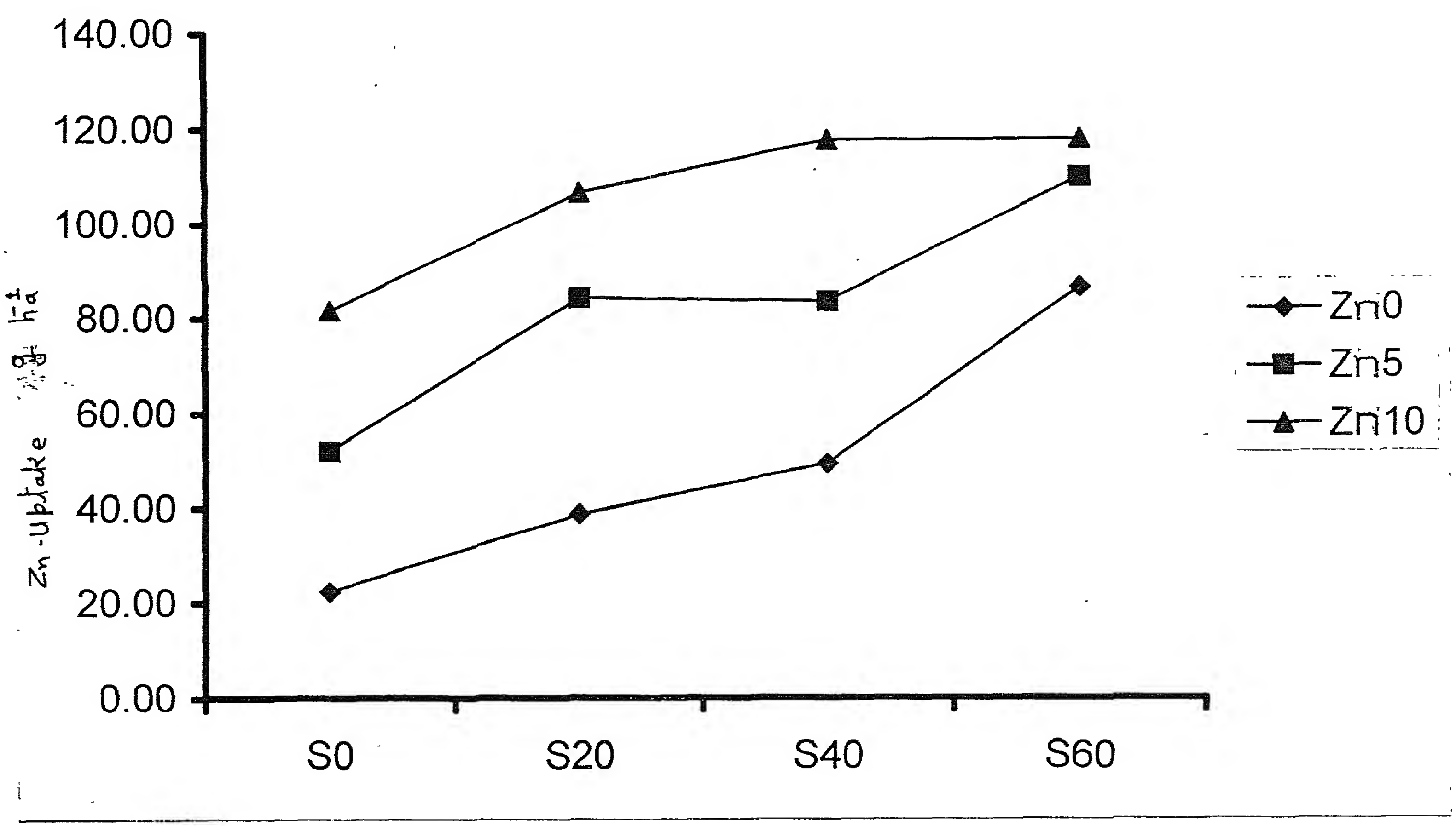

Figure: 4.2.5 Effect of S and Zn application on Zn-uptake by grains of mustard crop.

4.2.8 Effect of S and Zn application on Oil content in grains of mustard crop:

Glancing through the table 4.2.15, it appears that various doses of S and Zn have positively and significantly increased the oil content and thereby its quality in mustard. The oil content was observed in the mustard grain to the extent of 35.24% in the control set where no application of S and Zn was carried out. The maximum oil content (44.1%) was found in T_{12} treatment, which contained S_{60} Zn_{10} application. The increase in oil content may be due to mostly higher availability of S through application of higher level of sulphur (60kg ha^{-1}) individually and merely through S×Zn interaction. Therefore, various levels of sulphur was found significant, whereas different levels of zinc and S×Zn interaction remained non-significant at 5% level of significance.

Table 4.2.16: Effect of S and Zn application on Oil content in grains.

(Expressed in %)

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	35.24	38.45	41.35	43.56	39.65
Zn_5	35.73	36.34	42.27	43.83	39.54
Zn_{10}	36.31	40.80	42.94	44.08	41.03
Mean	35.76	38.53	42.19	43.82	

	SE (±)	**C.D. (5%)**
S	2.94	6.09
Zn	2.54	N.S.
S×Zn	5.09	N.S.

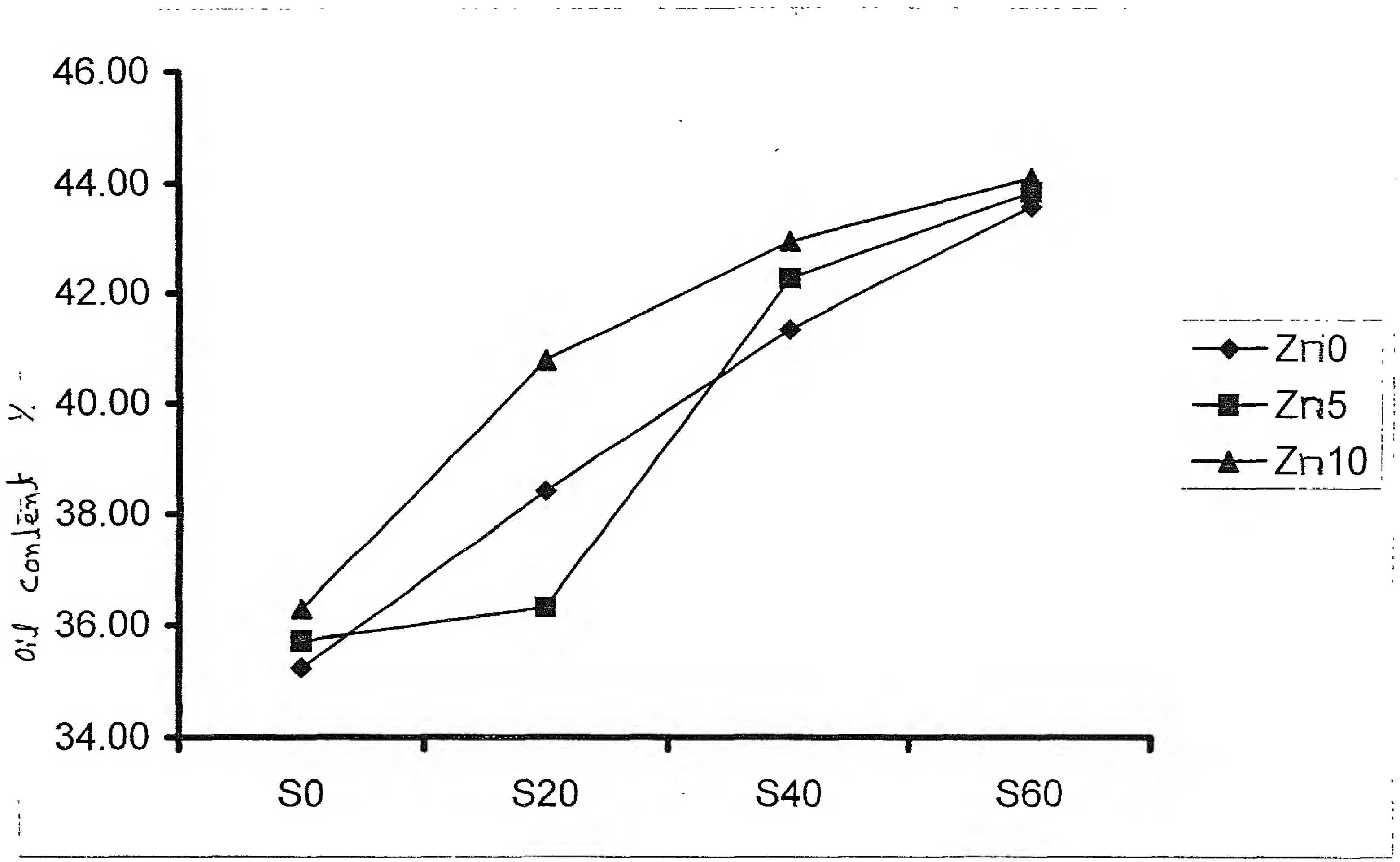

Figure: 4.2.6 Effect of S and Zn application on oil content in grains of mustard crop.

The oil content in grains of all the 3 treatments viz. T_{10}, T_{11} and T_{12} having 60 kg S ha^{-1} application were found to contain higher (43.56 to 44.08%) oil content than S_{40} and S_{20} treatment combinations. Sulphur individually increased the oil content by 23.6%, whereas zinc increased it individually by 3% only.

From the above findings it may be concluded that if any soil is not deficient of Zn then application of 60 kg S ha^{-1} would be more beneficial for the quality control of mustard crop. But the soil deficient of Zn should be applied optimum level of sulphur (< 60 kg S ha^{-1}) to check the antagonistic effect between S × Zn at higher levels (> 60 kg S ha^{-1}). Similar findings have been reported by Raut et al. (2000), Singh et al. (1998), Singh et al. (2000), Gupta et al. (1999), Singh et al. (1999), Sandhya et al. (1989) and Khurana et al. (1998).

4.2.9 Effect of S and Zn application on total and available nutrients in soil after harvesting

The soil samples were collected from each plots after harvest of mustard crop and treatment wise composite samples were processed for their analysis and recorded in table 4.2.16. It was observed that pH of the soil was slightly affected by sulphur fertilization and with S_{60} pH drop was noticed as 7.3 where the control soil was having 7.6 pH value. The total and available N content of the soil samples were estimated for each treatment and it was noticed that there was no significant variation in total N content whereas the available N content got increased in the S_{60}×Zn_{10} treatment may be due increased N availability by synergistic effect of S on N

Table 4.2.17 Amount of total and available nutrients in soil after harvesting mustard crop as influenced by S, Zn and N.P.K. treatments

Trea-tment	pH	N		P		K		S		Zn	
		total %	avail. ppm	total ppm	avail. ppm	total ppm	avail. ppm	total ppm	avail. ppm	total ppm	avail. ppm
T_1	7.6	0.07	35	198	9.2	395	67	105	5.2	70	0.65
T_2	7.6	0.07	37	195	7.5	395	65	127	3.9	71	0.74
T_3	7.6	0.07	36	196	6.3	395	68	152	4.4	76	0.78
T_4	7.5	0.08	36	195	14.6	396	63	150	8.7	70	0.68
T_5	7.5	0.07	37	196	11.2	397	70	159	7.2	72	0.77
T_6	7.5	0.07	38	196	9.8	396	62	150	6.1	78	0.79
T_7	7.4	0.08	37	200	15.4	395	62	138	13.2	71	0.70
T_8	7.4	0.07	39	298	12.5	397	63	161	14.3	73	0.77
T_9	7.4	0.08	42	195	10.9	396	60	160	13.7	78	0.82
T_{10}	7.3	0.08	40	201	16.5	398	64	165	17.5	71	0.80
T_{11}	7.3	0.08	38	202	13.6	395	67	160	15.3	72	0.84
T_{12}	7.3	0.07	47	196	9.0	396	69	161	13.6	79	0.87

availability. The increased crop yield may be due to higher availability of nutrients. The total P_2O_5 content of soil samples taken from different treatments has practically no change in their contents. The available P_2O_5 content was noticed to decrease where Zn fertilization was carried out whereas the S-application has helped in the raising the available P content. Similarly practically no variation was observed in total K_2O content of soil samples but in treatment no. 10 which contained $S_{60}\times Zn_{10}$ gave higher available K value.

The total S content of different soil samples collected from various treatments show an increase in total S with treatments receiving 60kg S ha^{-1} and available S was also found to raise with S-fertilization.

The total Zn content was estimated is soils after the harvest of mustard crop and found that Zn fertilized soils got slightly increased amount of Zn and the available Zn also was affected in the similar way.

EXPERIMENT NO.-3

A field experiment was conducted during 2001-02 with Chickpea (cv. Pusa - 261) as the test crop using different levels of S and Zn in soil and related investigations on plant analysis are presented in this experiment.

Table 4.3.1: Effect of S and Zn application on Chickpea height 30 D.A.S.

(Expressed in cms.)

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	14.80	15.95	16.54	17.43	16.18
Zn_5	15.13	16.10	16.92	17.58	16.43
Zn_{10}	15.56	16.61	17.10	18.60	16.97
Mean	15.16	16.22	16.85	17.87	

	SE (±)	C.D. (5%)
S	0.42	0.88
Zn	0.36	N.S.
S×Zn	0.74	N.S.

4.3.1 Effect of S and Zn application on Height Of Chickpea:

The height of chickpea crop as affected by different levels of S and Zn at 30 D.A.S. has been presented in table 4.3.1. The maximum height of plants (18.60 cm.) was observed at 60 kg S ha^{-1} and 10 kg Zn ha^{-1} as

against 14.80cm in control. The height of plant increased by 25.7% over the control. Influence of sulphur and zinc interaction on plant height appeared non-significant during 2001-2002. Data computed at 5% level of significance, revealed that the application of 60kg S alongwith 10kg Zn ha^{-1} was superior over the other treatments on height of plants. Patil (1979) also observed that Zn application has increased plant height of the crop.

Data presented in Table 4.3.2 at 60 D.A.S. indicates that the plant height increased significantly with increasing levels of sulphur and zinc. Increasing levels of sulphur increased the plant heights significantly over the control during 2001-2002 year. Though maximum height of plants was obtained with 60 kg S ha^{-1} and 5 kg Zn ha^{-1} application. The plant height increased by 32.6% at 60 kg S ha^{-1} and 5 kg Zn ha^{-1} over the control plant during the year. Chaniara and Damor (1982) have reported similar results.

Table 4.3.2: Effect of S and Zn application on chickpea height 60 D.A.S..

(Expressed in cms)

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	20.2	23.9	25.0	26.0	23.7
Zn_5	21.6	24.2	25.6	26.8	24.5
Zn_{10}	23.4	24.8	25.9	26.5	25.1
Mean	21.7	24.3	25.5	26.41	

	SE (±)	C.D. (5%)
S	0.47	0.97
Zn	0.41	0.84
S×Zn	0.81	N.S.

Table 4.3.3: Effect of S and Zn application on chickpea height 90 D.A.S.

(Expressed in cms)

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	30.5	32.6	35.0	39.9	34.5
Zn_5	31.2	33.4	36.1	40.5	35.3
Zn_{10}	32.3	34.6	37.5	39.4	35.9
Mean	31.3	33.5	36.2	39.93	

	SE (±)	**C.D. (5%)**
S	0.47	0.98
Zn	0.41	0.85
S×Zn	0.82	N.S.

Table 4.3.4: Effect of S and Zn application on chickpea height 120 D.A.S..

(Expressed in cms)

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	41.4	44.0	47.3	51.3	46.0
Zn_5	43.1	45.2	48.9	51.7	47.2
Zn_{10}	43.7	46.5	50.4	50.1	47.6
Mean	42.7	45.2	48.8	51.0	

	SE (±)	**C.D. (5%)**
S	0.45	0.94
Zn	0.39	0.81
S×Zn	0.79	1.63

The data presented in the table 4.3.3 clearly indicate that plant heights have increased significantly by the application of varying levels of S and Zn at 90 D.A.S.. The maximum height of plants (40.5cm.) obtained was at 60kg S and 5kg Zn ha^{-1} as against 30.5cm. in the control set. The plant height increased by 32.8% over the control. The increase in plant height with 60kg S ha^{-1} was at par with 40kg S ha^{-1} during 2001-02. The plant height increased at 60kg S and 5kg Zn ha^{-1} level may be due to more of sulphur which encourage the vegetative growth including elongation of the plants. Pandey (1996) have reported similar results that N and Zn application have increased the plant height.

Data interpreted in the table 4.3.4 at 120 D.A.S. clearly indicate that the height of plant increased significantly by 24.4% over the control. No particular trend amongst all the treatments could be observed in respect of height of the plants at various intervals.

Over all, it may be inferred that the height of chickpea increased by 24-33% at different stages of plant growth.

4.3.2 Effect of S and Zn application on number of branches per plant

It is clear from the table 4.3.5 those different doses of sulphur and zinc significantly influenced the number of branches per plant during the year 2001-02. On an average, the number of branches per plant increased linearly and significantly with an increase in sulphur and zinc doses upto 40 and 5kg levels respectively and thereafter a decrease was observed at their highest dose during the year. However, the number of branches per

plant remained almost same at both levels of sulphur dose upto 40 and 60kg ha^{-1}. Similarly both the doses of Zn upto 5kg and 10kg levels produced similar results for the number of the branches per plant. It may be noted that sulphur and Zn doses upto 40 and 5kg levels respectively are beneficial in producing more number of the branches per plant. The above findings indicate that both sulphur and zinc increased the number of branches by 42.9% over the control with the application of 40kg S and 5kg Zn ha^{-1} level.

Table 4.3.5: Effect of S and Zn application on number of branches of chickpea crop.

(Expressed in Plant^{-1})

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	23.3	27.3	29.3	30.0	27.4
Zn_5	26.6	32.6	33.3	33.3	31.4
Zn_{10}	27.6	32.6	33.6	32.3	31.5
Mean	25.8	30.8	32.1	31.8	

	SE (±)	C.D. (5%)
S	0.39	0.82
Zn	0.34	0.70
S×Zn	0.68	N.S.

The average number of branches ranged from 23.3 to 30.0 when the dose of sulphur increased upto 60kg ha^{-1} without zinc application. However, it increased from 23.3 to 27.3% was noticed when the dose of zinc increased upto 10kg ha^{-1} without sulphur application. Similar

findings have been reported by Chaniara and Damor (1982) and Swarnkar (1984).

4.3.3 Effect of S and Zn application on Grain Yield:

The data on grain yield as influenced by different doses of sulphur and zinc have been given in table 4.3.6. The different doses of sulphur and zinc influenced the grain yield significantly. However, their interaction showed non-significant effect. On an average the grain yield increased linearly and significantly upto 40 kg S and 5 Kg Zn ha^{-1} application, and thereafter, decreased upto 60 kg S and 10 kg Zn level. On an average the highest

Table 4.3.6: Effect of S and Zn application on grain yield of chickpea crop.

(Expressed in q ha^{-1})

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	18.90	21.78	23.90	24.27	22.2
Zn_5	22.05	25.82	26.83	25.76	25.1
Zn_{10}	22.32	25.65	26.64	25.36	24.9
Mean	21.1	24.4	25.8	25.1	

	SE (±)	**C.D. (5%)**
S	0.32	0.68
Zn	0.28	0.58
S×Zn	0.56	N.S.

grain yield of 23.9 q ha^{-1} recorded at 40 kg S ha^{-1} was computed 26.4% higher than the lowest grain yield of 18.9 q ha^{-1} recorded at control set.

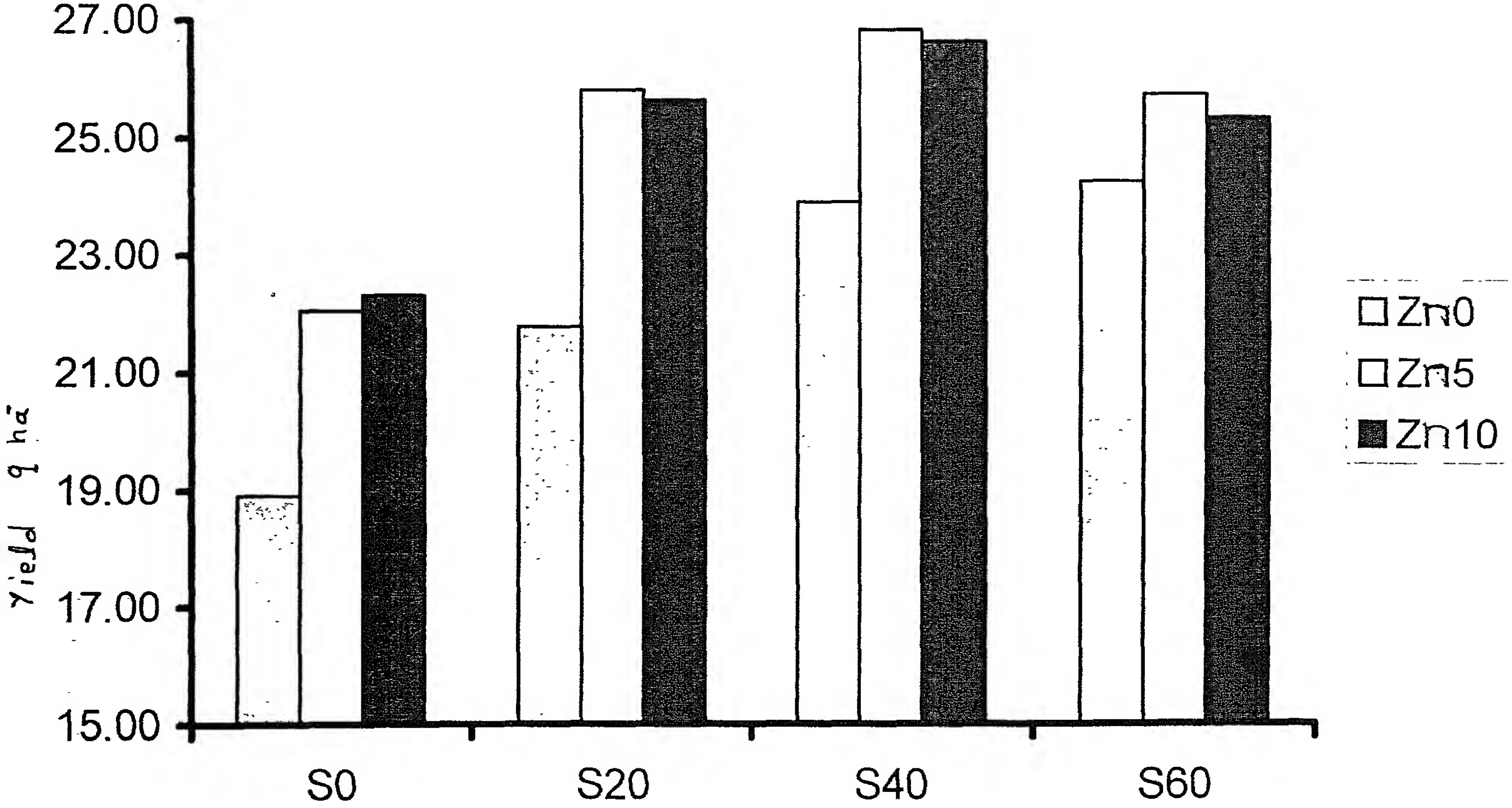

Figure: 4.3.1 Effect of S and Zn application on grains yield of chickpea crop.

Likewise, on an average, the highest grain yield of 22.3 q ha^{-1} obtained at 10kg Zn ha^{-1} was computed 17.9% higher that the control set i.e. no. sulphur and zinc application during the year 2001-02.

Thus it is obvious that response of sulphur application in comparison to zinc was of higher magnitude. Similar findings have been reported by Jaggi and Sharma (1999) and Khurana et al. (1995).

4.3.4 Effect of S and Zn application on Straw Yield:

It is clear from the table 4.3.7 that likewise grain yield, straw yield was also significantly affected by application of different doses of sulphur

Table 4.3.7: Effect of S and Zinc application on straw yield of chickpea crop.

(Expressed in q ha^{-1})

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	28.36	32.65	36.07	36.48	33.4
Zn_5	33.69	37.78	40.58	38.57	37.6
Zn_{10}	34.50	37.50	39.50	37.82	37.3
Mean	32.2	35.9	38.7	37.6	

	SE (±)	**C.D. (5%)**
S	0.37	0.77
Zn	0.32	0.66
S×Zn	0.64	N.S.

and zinc. The interaction between sulphur and zinc (S×Zn) was observed non-significant. On an average the straw yield increased upto 40 kg Kg S

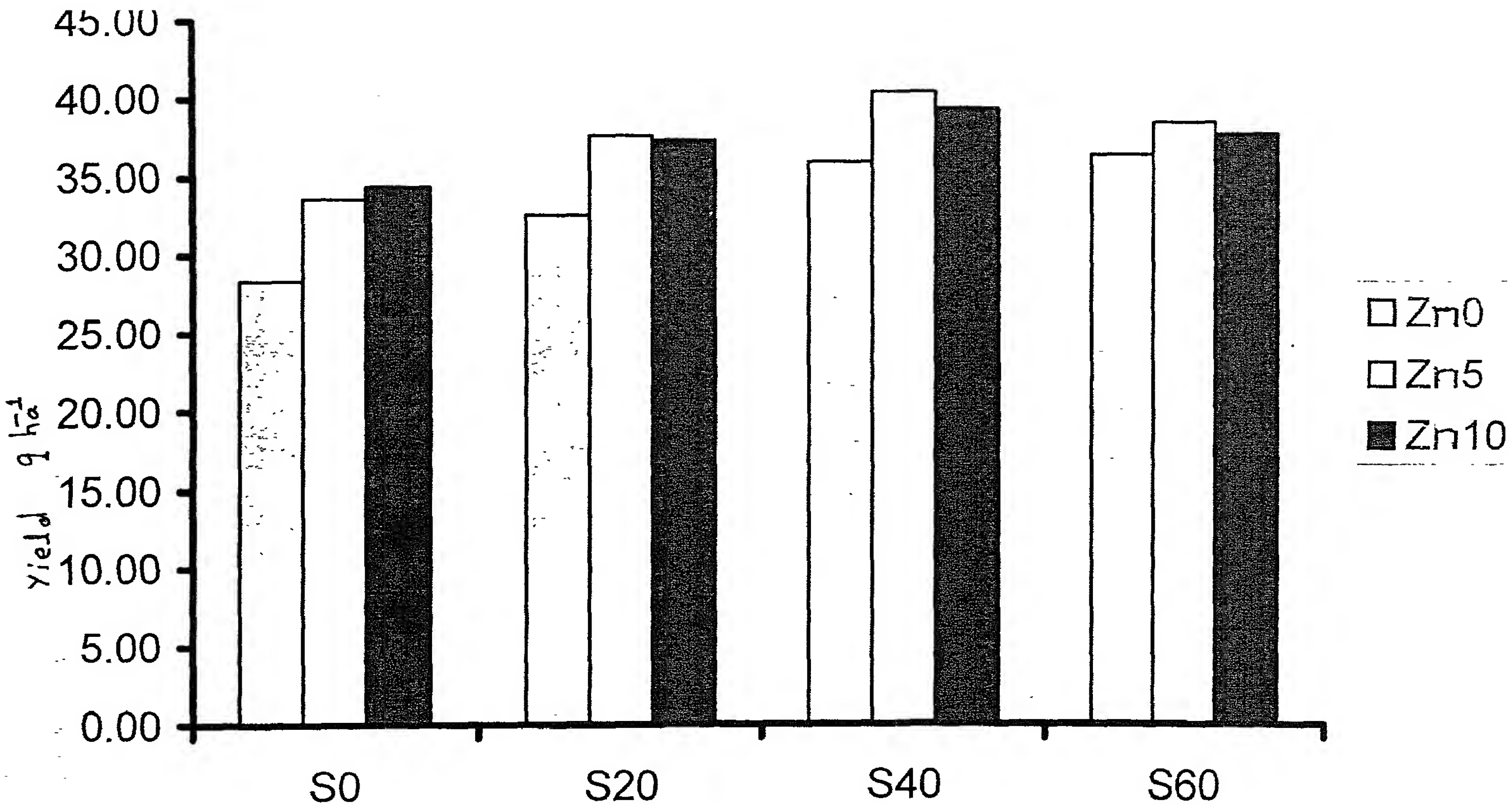

Figure: 4.3.2 Effect of S and Zn application on straw yield of chickpea crop.

and 5 Kg Zn ha^{-1} application linearly and significantly and thereafter the decrease was observed not significant from their highest doses. The highest straw yield 36.5 q ha^{-1} recorded at 60 kg S ha^{-1} and was calculated 28.5% higher than the lowest straw yield of 28.4 q ha^{-1} recorded in control i.e. with no sulphur application. Similarly on an average, the highest straw yield of 34.5 q ha^{-1} obtained with 10 kg Zn application was computed 21.5 higher than the control set with no S and Zn application. Similar results have been reported by Rathore and Maliwal (1990) and Singh et al. (1993).

4.3.5 Effect of S and Zn application on nitrogen content in grain of chick pea:

Table 4.3.8: Effect of S and Zn application on N content in grain of chickpea.

(Expressed in %)

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	2.90	3.15	3.25	3.29	3.1
Zn_5	3.00	3.35	3.39	3.40	3.2
Zn_{10}	3.13	3.37	3.38	3.38	3.3
Mean	3.0	3.3	3.3	3.3	

	SE (±)	C.D. (5%)
S	0.11	0.23
Zn	0.09	0.20
S×Zn	0.19	N.S.

The results obtained with N content of the test crop mentioned in

table 4.3.8 indicate that both sulphur and zinc separately increased the nitrogen content of the grain by 13.4 and 7.9% respectively, over the control. The nitrogen content in grain got increased by 17.2% at 40 kg S and 10kg Zn ha^{-1}.

The data of N content presented in Table 4.3.8 clearly indicated that nitrogen content in grain significantly influenced by sulphur and zinc during the year 2001-2002. On an average, the nitrogen content increased significantly upto 17.2% in grain at 60kg S and 5 kg Zn application ha^{-1}. Moreover the nitrogen content at 40 and 60 kg S, and 5 and 10kg Zn ha^{-1} levels were statistically at par in chickpea grain during the year. The results are in conformity with the findings earlier reported by Kodamdhad et al. (1996) and Babhulkar et al. (2000).

4.3.6 Effect of S and Zn application on nitrogen Uptake in Grain of Chickpea:

The relevant data given in the table 4.3.9 revealed that the uptake of nitrogen in grain is generally positive and significant at different levels of sulphur and zinc. However, the interaction between N×S was not significant. A similar result was reported by Masih et al. (1991). It was observed that nitrogen uptake increased significantly upto 60kg S and 5kg Zn levels and thereafter decreased antagonistically at 60kg S and 10kg Zn ha^{-1} levels. The highest nitrogen uptake (mean) of 79.9 kg ha^{-1} recorded at 60kg S ha^{-1} was computed 44.9 percent higher than the lowest of 55.15 kg ha^{-1} recorded at control. Similarly the highest N-uptake (mean) of 69.89 kg ha^{-1}. recorded in 10kg Zn ha^{-1} was computed 26.7% higher over the control.

Table 4.3.9: Effect of S and Zn application on N-Uptake in grain of chickpea.

(Expressed in kg ha^{-1})

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	55.15	68.62	77.60	79.91	70.32
Zn_5	66.18	86.38	91.09	87.60	82.81
Zn_{10}	69.89	86.42	90.06	85.71	83.02
Mean	63.74	80.47	86.25	84.40	

	SE (±)	**C.D. (5%)**
S	2.72	5.64
Zn	2.35	5.89
S×Zn	4.71	N.S.

The combined application of 40 kg sulphur and 5kg zinc ha^{-1} produced the highest uptake of 91.09 kg ha^{-1} nitrogen in grain. The combined application of 40kg S and 5kg Zn ha^{-1} gave 26.7% extra increase in nitrogen uptake than the sum of their individual effects in chickpea. Similar result was reported by Hazra (1988).

Thus, N+S application produced synergistic effect has reported by Sachdev and Deb (1990). It is obvious that application of sulphur has more remarkable effect on uptake of nitrogen in comparison to Zn application.

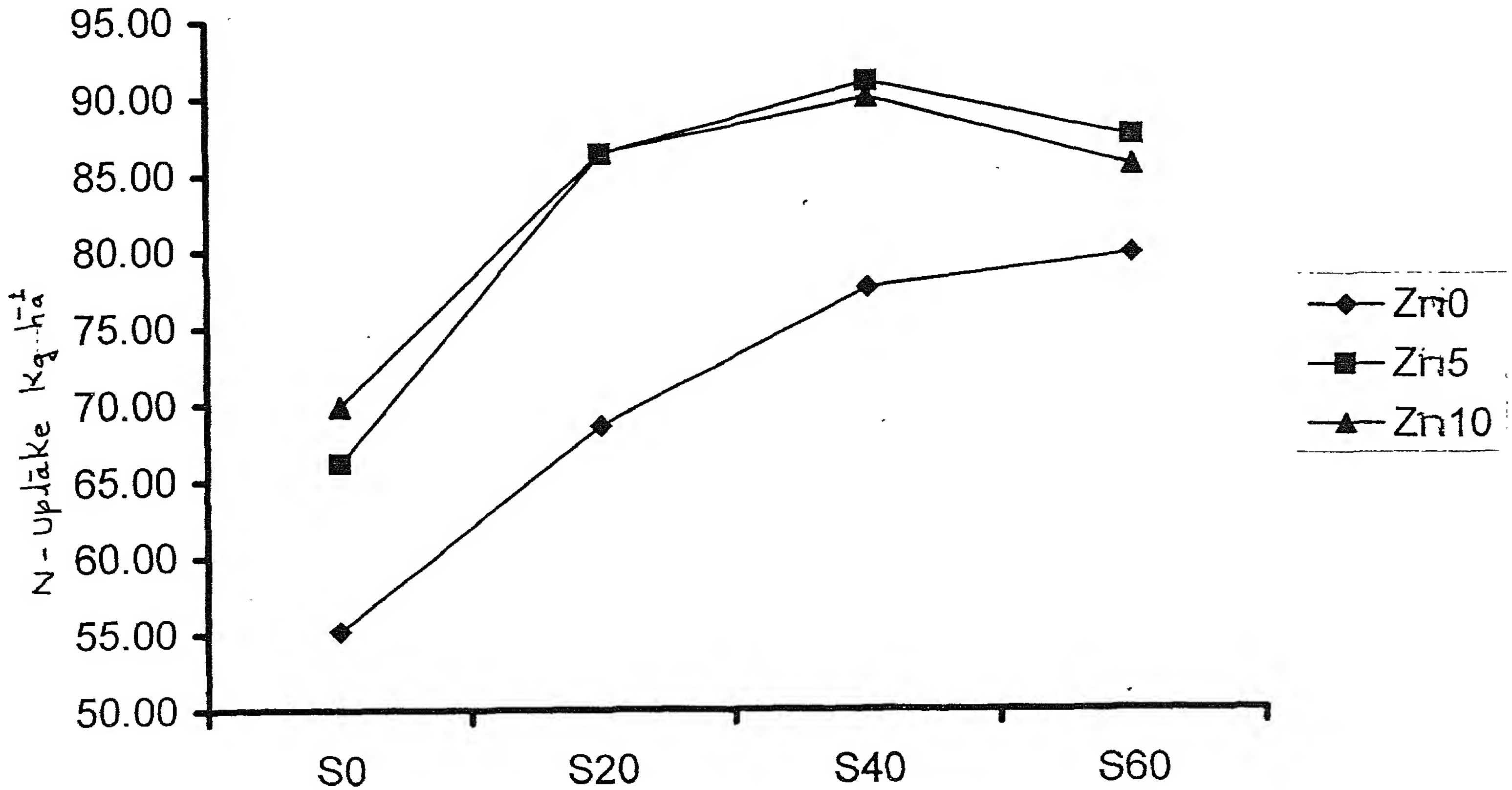

Figure: 4.3.3 Effect of S and Zn application on N-Uptake in grain of chickpea crop.

4.3.7 Effect of S and Zn application on Phosphorus - Content in Chickpea:

Maximum content of phosphorus was observed in grain at 40 kg S ha^{-1} application indicating 15% increase over the control whereas it was observed minimum at 10kg Zn ha^{-1} application i.e. 7.5% decrease over the control.

The P content in grain of the chickpea with 10kg Zn ha^{-1} application found to reduce the P-uptake indicating antagonistic response as the content was detected at lower level than the control set.

Table 4.3.10: Effect of S and Zinc application on P content in grain of chickpea.

(Expressed in %)

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	0.40	0.44	0.46	0.44	0.43
Zn_5	0.37	0.42	0.42	0.41	0.40
Zn_{10}	0.37	0.39	0.39	0.38	0.38
Mean	0.38	0.41	0.42	0.41	

	SE (±)	**C.D. (5%)**
S	0.02	0.05
Zn	0.01	0.04
S×Zn	0.04	N.S.

The effect of varying levels of sulphur and zinc on phosphorus content of grain is recorded in Table 4.3.10. The data on P content of the crop harvest containing grain got significantly influenced by sulphur and zinc application. However interaction of different doses of sulphur and zinc application did not have any significant effect. It is interesting to mention that with increasing levels of zinc, P-concentration in grain yield decreased significantly, being highest at control and lowest at 10kg Zn ha^{-1}. Thus zinc application exhibited antagonistic relationship with phosphorus absorption. On the contrary sulphur application shows synergistic relationship with absorption of phosphorus at grain yield

4.3.8 Effect of S and Zn application on P-uptake in grain of Chickpea:

Table 4.3.11: Effect of S and Zinc application on P-Uptake in grain.

(Expressed in kg ha^{-1})

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	7.53	9.57	10.97	10.67	9.68
Zn_5	8.13	10.88	11.29	10.57	10.21
Zn_{10}	8.25	9.98	10.40	9.66	9.57
Mean	7.97	10.14	10.88	10.30	

	SE (±)	C.D. (5%)
S	0.58	1.20
Zn	0.50	N.S.
S×Zn	1.00	N.S.

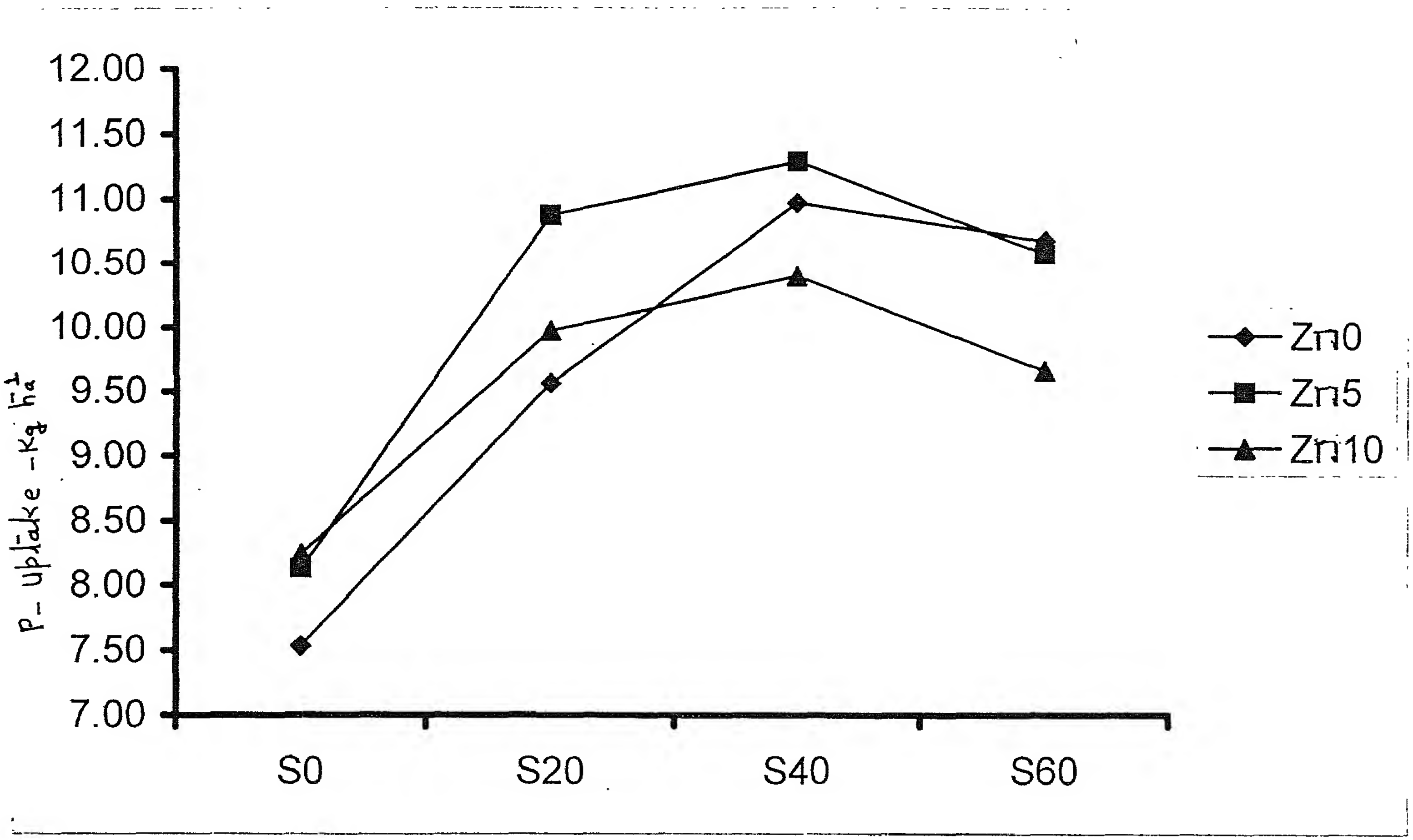

Figure: 4.3.4 Effect of S and Zn application on P-Uptake in grain of chickpea crop.

The table 4.3.11 indicates that the P-uptake increased significantly in linear order with increasing doses of sulphur upto 40 kg level and thereafter decreased onward. The uptake of phosphorus in relation to zinc increased upto 5kg level and thereafter decreased onward. A positive interaction was observed between P×S upto the level of 40kg sulphur and between P×Zn upto the level of 5kg Zn ha^{-1} and beyond the level of 40 kg S and 5kg Zn, the interaction was observed negative. The highest P-uptake of 10.97 kg ha^{-1} recorded at 40 kg S level was computed 46.2% higher over the control, whereas the highest P-uptake of 8.26 kg ha^{-1} recorded at 10kg Zn ha^{-1} was computed 9.6% higher over the control only. The combined application of 40kg S and 5kg Zn gave the ever highest P-uptake of 11.29 kg ha^{-1} which was computed 18.2% extra than the sum of their individual effects.

From the above findings both positive and negative interactions have been found between P and S that definitely depends on their rate of application. P×S interaction is synergistic at low medium levels (40 kg S and 5kg Zn ha^{-1}) and antagonistic only at higher levels, usually at 60 or more kg S ha^{-1} for chickpea. Similar results have been reported by Biswas and Prasad 1991, Tandon 1991, Pasricha et al. 1987 and Singh et al. 1997.

The above research studies suggest that soils low in sulphur may not be able to supply crop requirements when large applications of P-fertilizers are made. The large application of P-fertilizers further creates S deficiency by increasing the release of SO_4-S into soil solution.

Thus the nature of P×S interaction depends on their rate of application.

4.3.9 Effect of S and Zn application on Potassium Content in Chickpea:

The maximum content of potassium was observed in grain at both the levels as (i) 40 kg S and 10kg Zn ha^{-1} and (ii) 60 kg S and 5kg Zn ha^{-1} which indicated 18.2% increase over the control. Application of 10kg Zn ha^{-1} only indicated 8.3% and 11.4% increase in potassium content in grain.

Table 4.3.12: Effect of S and Zinc application on K content in grain of chickpea.

(Expressed in %)

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	1.32	1.42	1.53	1.56	1.45
Zn_5	1.45	1.57	1.67	1.67	1.59
Zn_{10}	1.47	1.59	1.68	1.66	1.60
Mean	1.41	1.52	1.62	1.63	

	SE (±)	**C.D. (5%)**
S	0.03	0.07
Zn	0.03	0.06
S×Zn	0.06	N.S.

Likewise contents of nitrogen and phosphorus the potassium was also significantly affected by the application of different doses of sulphur and zinc. The grain and straw yield during the year as affected by different S and Zn combination recorded in table 4.3.12. It is obvious that potassium content showed increasing trend with the application of

increasing levels of sulphur and zinc in grain S of chickpea during the year. Purakayastha and Nad (1998) have also reported similar findings in mustard crop.

4.3.10 Effect of S and Zn application on K-Uptake in grain of Chickpea:

Table 4.3.13: Effect of S and Zinc application on K-Uptake in grain of chickpea.

(Expressed in kg ha^{-1})

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	24.98	30.93	36.53	37.91	32.58
Zn_5	31.99	40.60	44.79	43.00	40.09
Zn_{10}	32.81	40.78	44.75	42.08	40.10
Mean	29.92	37.43	42.02	40.99	

	SE (±)	C.D. (5%)
S	1.02	2.12
Zn	0.88	1.84
S×Zn	1.77	N.S.

It is obvious from the table 4.3.13 that grain of chickpea responded positively to the combined application of S and Zn resulting in maximum K-uptake of 44.79 kg ha^{-1} at 40 kg S and 5kg Zn level. The increased K-uptake of 37.91kg ha^{-1} recorded at 60kg S level was computed 51.7% higher over the control. Likewise, the increased K-uptake of 32.81kg ha^{-1} recorded at 10kg Zn ha^{-1} was computed 31.3% higher over the control. Therefore the magnitude of S in comparison to Zn was observed to be

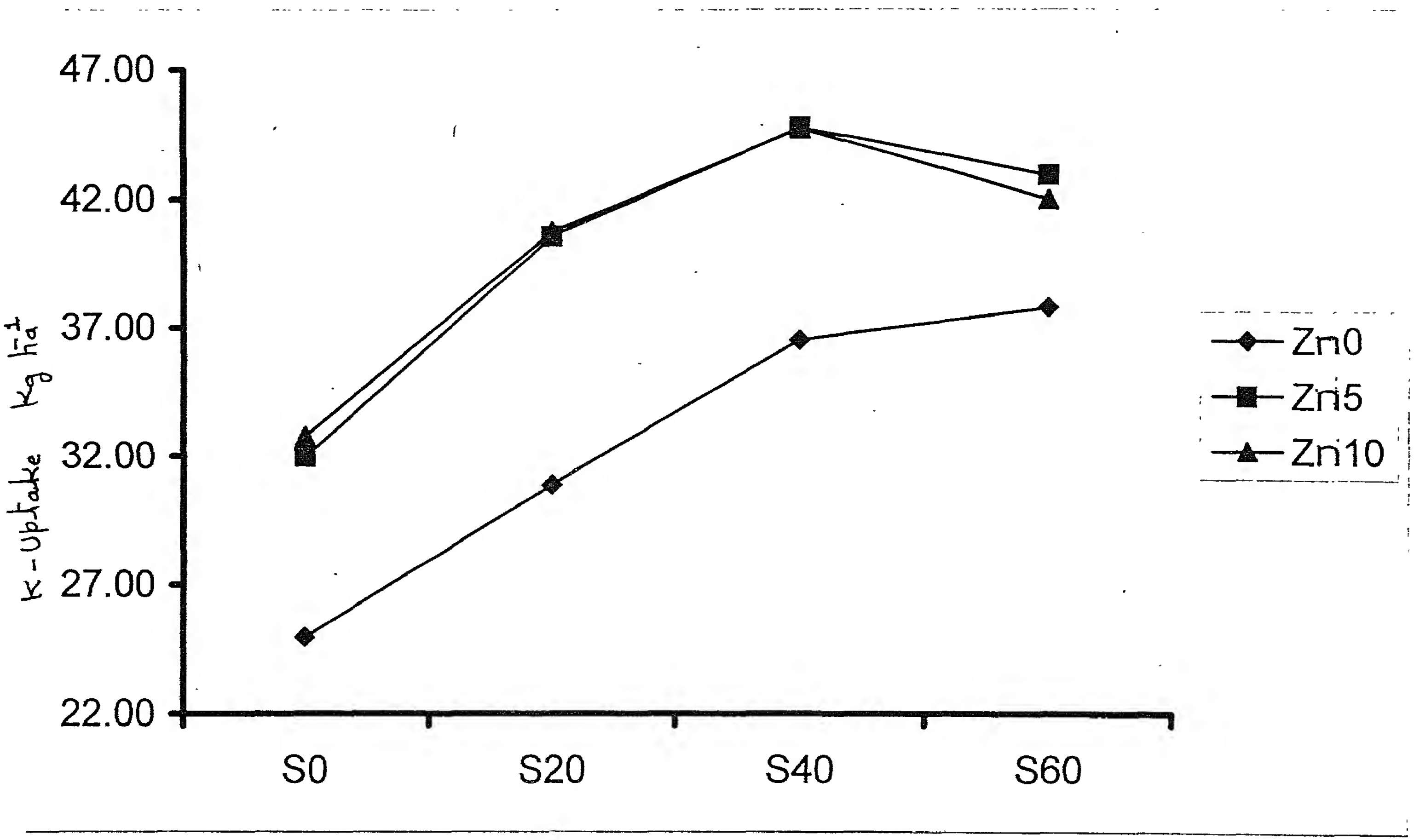

Figure: 4.3.5 Effect of S and Zn application on K-Uptake in grain of chickpea crop.

higher. The combined effect of 40 kg S and 5kg Zn gave the highest K-uptake of 44.79kg ha^{-1} which was computed 79.3% higher over the control.

Thus increasing levels of S significantly enhanced the K-uptake by grain showing synergistic effect at lower level. The positive effect of S and Zn addition on K-uptake have also been reported by Barsoom et al. (1996) and Fecenko and Lozek (1998).

4.3.11 Effect of S and Zn application on sulphur content in Chickpea:

The maximum content of sulphur was observed at 60kg S ha^{-1} application level indicates 55.2% increase over the control in grain.

Table 4.3.14: Effect of S and Zinc application on S-Content in grain of chickpea.

(Expressed in %)

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	0.29	0.39	0.43	0.45	0.39
Zn_5	0.26	0.38	0.41	0.43	0.37
Zn_{10}	0.25	0.36	0.40	0.39	0.35
Mean	0.26	0.37	0.41	0.42	

	SE (±)	**C.D. (5%)**
S	0.04	0.08
Zn	0.03	0.07
S×Zn	0.07	N.S.

Application of 10kg Zn ha^{-1} found to decrease the sulphur content by 13.8% in grain. The content of sulphur almost remained in the range of 0.18-0.20% at 40-60 kg S ha^{-1} application with or without zinc application.

The data pertaining to the effect of application of graded doses of sulphur and zinc on sulphur contents in grain yield during the year have been presented in Table 4.3.14. It is visualized from the table that sulphur content showed linear relationship with its application being lowest at control and highest at 60kg S ha^{-1} in grain yield of crop during the year. On the other hand with the application of increasing levels of zinc concentration of in grains declined linearly, showing antagonistic relationship between sulphur and zinc. However from the interaction effect (Fig.......), it is also obvious that likewise N, P and K at different levels of S and Zn did not have significant effect on sulphur contents. However addition of Zn depressed the absorption of S (Kumar and Singh 1980) and Tripathi et al (1997) and also reported by Jaggi and Sharma (1999).

4.3.12 Effect of S and Zn application on S- Uptake in Grain of Chickpea:

It is clear from the table 4.3.15 that uptake of sulphur increased from 5.48kg to 10.97kg ha^{-1} as the doses of sulphur increased upto 60kg level which was computed two times higher over the control. The successive increase in zinc level from 0 to 10 kg ha^{-1} significantly increased the S-uptake upto the level of 5kg Zn ha^{-1} (from 8.79 to 9.412

kg S ha^{-1}) and then decreased significantly at 10 kg zinc ha^{-1} level (from 9.41 to 8.81 kg S ha^{-1}). The highest uptake of sulphur of 11.06 kg ha^{-1} was recorded at 60kg S and 5kg Zn level which was computed two times higher over the control. The mean content of S-uptake ranged from 8.79 to 9.41 kg ha^{-1} as the doses of zinc increased upto 5kg level which was computed 6.9% higher from 0 level Zn and then the S-uptake decreased by 6.3%. Thus Zn did not shows any definite trend in the uptake of sulphur in grain of chickpea. There was positive effect of Zn and S on sulphur-uptake but increasing supply of zinc above 5kg level caused significant decrease of S-uptake in the grain. Similar results have been reported by Chatterjee et al. (1998), Dangarwala (1994) and Krishnasamy et al. (1994).

Table 4.3.15: Effect of S and Zinc application on S-Uptake by grain of Chickpea.

(Expressed in kg/ha^{-1})

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	5.48	8.47	10.25	10.97	8.79
Zn_5	5.74	9.87	10.98	11.06	9.41
Zn_{10}	5.56	9.21	10.64	9.85	8.82
Mean	5.59	9.18	10.62	10.63	

	SE (±)	**C.D. (5%)**
S	1.02	2.12
Zn	0.88	1.83
S×Zn	1.77	N.S.

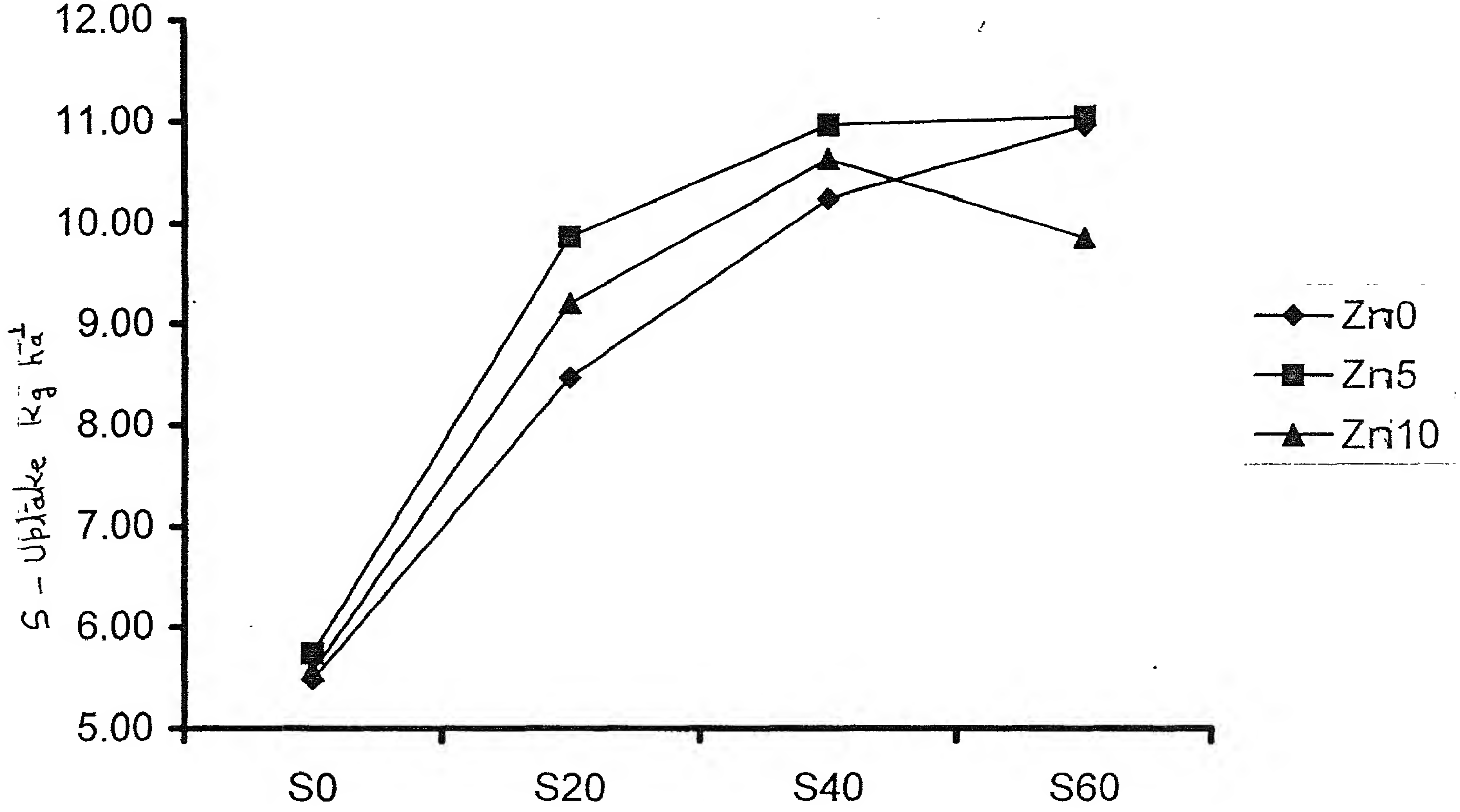

Figure: 4.3.6 Effect of S and Zn application on S-Uptake in grain of chickpea crop.

4.3.13 Effect of S and Zn application on zinc content in Chickpea:

Zinc content was observed to be maximum at 20kg S and 10kg Zn ha^{-1} level application indicating 132.9% increase over the control in grain. It is interesting to note that zinc content in grain was observed to be maximum (37.5ppm) at 20kg S ha^{-1} level while it started decreasing from 37.5 to 32.8ppm beyond the level of 20kg S ha-$^{-1}$ along with 5-10kg Zn ha^{-1} application. Thus addition of 40kg S compared with treatment 6 (T_6-S_{20} Zn_{10}) causes 4.3ppm (11.5%) decrease in Zn content in the grain of chickpea.

Table 4.3.16: Effect of S and Zn application on Zn-content in grain of chickpea.

(Expressed in ppm)

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	16.1	17.3	17.7	16.0	16.78
Zn_5	35.6	36.7	36.0	32.8	35.28
Zn_{10}	36.4	37.5	36.4	33.2	35.88
Mean	29.37	30.50	30.03	27.33	

	SE (±)	C.D. (5%)
S	0.44	0.91
Zn	0.38	0.78
S×Zn	0.76	N.S.

An appraisal of the data given in Table 4.3.16 shows that zinc contents in grain yield of crop during the year was influenced significantly by the application of graded doses of sulphur and zinc. However, their interaction influenced the zinc content non-significantly. It is peculiar to record that on an average zinc content in comparison to control got increased significantly at 20kg S level and thereafter decreased upto 60 kg S levels in grain yield exhibiting antagonistic relationship between sulphur and zinc. As expected the concentration of zinc increased linearly and significantly with the application of its increasing levels in grain yield of crop during the year. The above results are in conformity with the findings earlier reported by Singh et al. (1986).

4.3.14 Effect of S and Zn application on Zn-uptake in grain of chickpea:

Zn uptake in grain has been given in the table 4.3.17. The effect of S, Zn, and S×Zn interaction has been found significant with the uptake of Zn in grain of chickpea. On an average, S addition increased the Zn-uptake upto 78.75g recorded at 40kg S ha^{-1} and thereafter decreased to 69.15g at 60kg S ha^{-1} level. On the other hand, a linear increasing trend in Zn-uptake was observed with increasing doses of Zn, resulting in lowest (30.47g) at control and highest (81.25g) at 10 kg Zn ha^{-1} level during the year. On an average, the highest uptake of 42.34g. Zn recorded at 40kg S was computed 38.9% higher over the control whereas the highest uptake of 81.25g zinc recorded at 10kg Zn ha^{-1} level was computed 166.6% higher over the control. The combined doses of 40Kg S and 10kg Zn gave

the highest ever uptake of Zn (97.19g), which was, computed 218.9% higher over the control. The combined application of 40kg S and 10 kg Zn gave 57.3% extra uptake of Zn than sum of their individual effects. Similar results have been reported by Gupta et al. (1999) and Singhal and Rattan (1999).

Table 4.3.17: Effect of S and Zn application on Zn-Uptake by grain of Chickpea.

(Expressed in g ha^{-1})

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	30.47	37.69	42.34	38.80	37.33
Zn_5	78.53	94.70	96.73	84.48	88.61
Zn_{10}	81.25	96.17	97.19	84.17	89.70
Mean	63.42	76.19	78.75	69.15	

	SE (±)	**C.D. (5%)**
S	1.49	3.09
Zn	1.29	2.68
S×Zn	2.59	5.36

It is remarkable to mention that the increase in zinc uptake was of higher magnitude at first level of S and Zn in comparison to control than in comparison between two levels of each of these nutrients.

Thus Zn showed higher magnitude in comparison to sulphur in Zn-uptake of the plant. It may be concluded that successive increase in S level from 0 to 40kg ha^{-1} progressively and significantly increased the

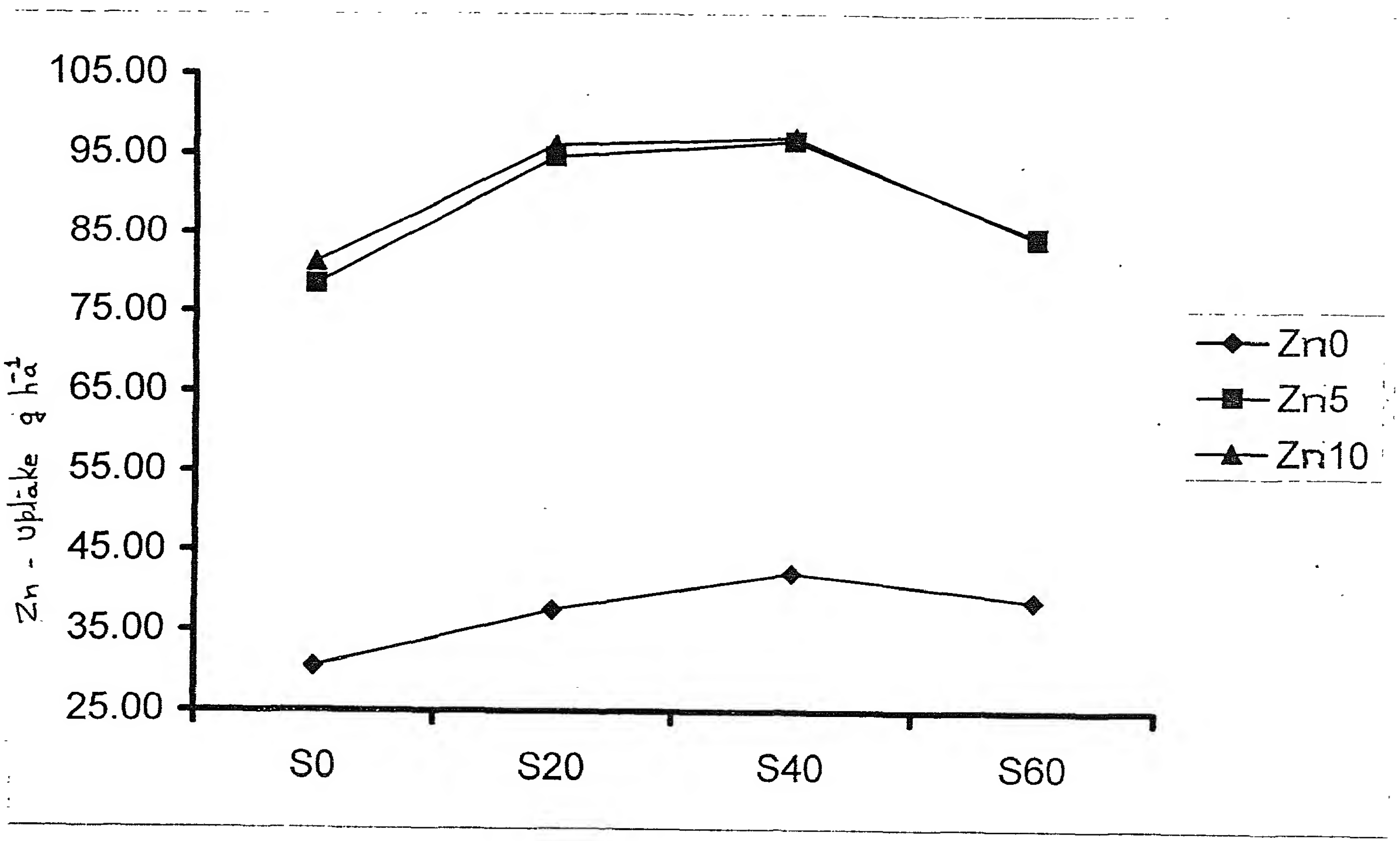

Figure: 4.3.7 Effect of S and Zn application on Zn-Uptake in grain of chickpea crop.

zinc uptake upto the level of 112.05 g Zn showing synergistic effect at lower level and further increase in S level decreased Zn-uptake significantly during the year showing antagonistic effect at higher level. Singh et al. (1997), Barsoom et al. (1996) and Fecenko and Lozek (1998) have reported similar results.

4.3.15 Effect of S and Zn application on crude protein content in chickpea:

Table 4.3.18: Effect of S and Zinc application on crude Protein-content in grain of chickpea.

(Expressed in %)

Treatment	S_0	S_{20}	S_{40}	S_{60}	Mean
Zn_0	18.12	19.68	20.31	20.56	19.67
Zn_5	18.75	20.94	21.19	21.25	20.53
Zn_{10}	19.56	21.06	21.13	21.13	20.72
Mean	18.81	20.56	20.88	20.98	

	SE (±)	C.D. (5%)
S	0.70	1.46
Zn	0.60	1.26
S×Zn	1.22	N.S.

The data on crude protein content in grain of chickpea has been given in table 4.3.18 clearly indicate that its content was significantly affected by different doses of sulphur and zinc. Sulphur application has an

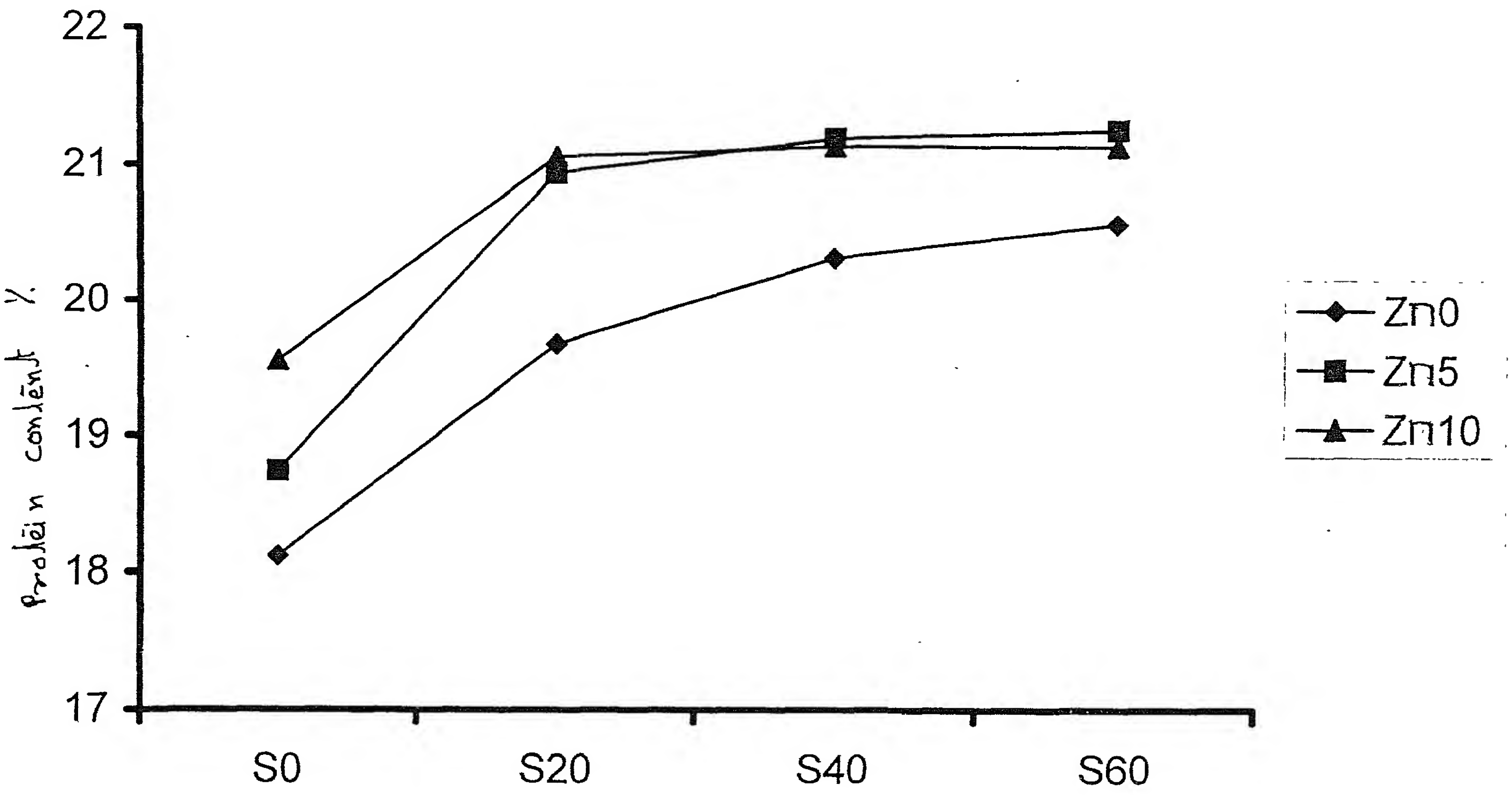

Figure: 4.3.8 **Effect of S and Zn application on protein content in grain of chickpea crop.**

increasing effect of protein content resulting in lowest protein content at the control set and highest at 60kg level. Similarly zinc application also increased the protein content significantly. The protein content at 40 and 60kg Sulphur, and 5 and 10 kg Zn levels were statistically at par during the year. The highest protein contents (21.25%) was observed at 60kg S and 5kg Zn level which was computed 17.2% higher over the control. On an average the high protein content of 20.5% recorded at 60 kg S ha^{-1} were computed 13.5% higher over the control. Likewise the mean highest protein content of 19.56 per cent recorded at 10kg Zn ha^{-1} were just 8 percent higher over the lowest protein content at control set i.e. with no zinc application.

Thus it may be concluded that response of sulphur application on crude protein content in comparison to zinc was of higher in magnitude.

Similar findings have also been reported by Singh and Ram (1990), Ram and Dwivedi (1992) and Raut et al (2000) that maximum protein percentage was observed with 60 kg sulphur ha^{-1}. However increase in Zn levels did not have marked effect on protein content.

4.3.16 Effect of S and Z application on Total and available nutrients in soil after harvesting

The soil samples were collected from each plot after the harvest of chickpea crop and the composite sample for each treatment was processed for analysis for different nutrients for their total and available contents viz. N,P,K, S and Zn. The data containing soil contents have been presented in table 4.3.19.

Table 4.3.19 Amount of total and available nutrients in soil after harvesting chickpea crop as influenced by S, Zn and N.P.K. treatments

Trea-tment	pH	N		P		K		S		Zn	
		total %	avail. ppm	total ppm	avail. ppm	total ppm	avail. ppm	total ppm	avail. ppm	total ppm	avail. ppm
T_1	7.8	0.08	45	190	8.5	391	63	115	5.1	72	0.60
T_2	7.8	0.08	46	191	7.2	391	63	130	5.0	73	0.64
T_3	7.8	0.08	45	193	6.9	391	63	137	5.3	77	0.75
T_4	7.7	0.09	47	195	13.4	392	64	148	6.0	71	0.65
T_5	7.7	0.08	48	195	10.3	392	67	150	6.3	74	0.70
T_6	7.7	0.09	50	194	9.5	391	65	150	5.9	78	0.77
T_7	7.6	0.08	51	192	13.0	393	64	263	7.2	74	0.70
T_8	7.6	0.07	53	195	10.8	390	62	162	7.1	76	0.71
T_9	7.6	0.07	52	197	10.3	392	65	163	7.4	78	0.80
T_{10}	7.5	0.08	51	197	13.5	393	65	168	10.3	76	0.70
T_{11}	7.5	0.09	50	196	11.6	392	64	167	10.1	78	0.74
T_{12}	7.5	0.07	52	193	10.4	392	63	166	9.8	80	0.81

CHAPTER-V

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

The present investigation on S and Zn studies in soil plant relationship with following objectives have been assigned in the thesis to undertake some laboratory and field trial experiments: -

(1) Distribution of sulphur and zinc in some soils of Allahabad and Fatehpur district for assessment of S and Zn levels. (Laboratory experiment).

(2a) To study the response of S and Zn application in mustard in a field trial on yield and yield attributing characteristics.

(2b) S-uptake, Zn-uptake and oil content in mustard grains.

(2c) Effect of different treatments on soil after harvest of the crop.

(3a) To study response of S and Zn application in chickpea crop in a field trial on yield and yield attributing characteristics.

(3b) Uptake of N, P, K, S and Zn by chickpea crop and protein content in grains.

(3c) Effect of different treatments on soil after harvesting.

A field survey of different blocks in Allahabad and Fatehpur district was carried out to study the available S and Zn status of soils. Since very little information regarding the distribution of both S and Zn in the soils of this region was available, the present survey was carried out with the objectives (i) to collect the information regarding the status of S and Zn and (ii) to locate the S and Zn deficient area in this region.

The available S content of soils of district Allahabad and Fatehpur ranged from 2.4 to 75.4 and 2.4 to 81.2ppm with mean value of 14.25 and 13.61ppm respectively. The highest mean (18.12 ppm) of available S was recorded at Mau-Aima block of Allahabad whereas the lowest mean (12.39ppm) of available S was observed at Bahadurpur block in Fatehpur district. A significant response of S application may be obtained in this region. The total information is based on the analysis of 340 soil samples. Out of 340 soil samples, 200 soil samples were taken from block of Allahabad district and the remaining 140 soil samples were taken from different blocks of Fatehpur district.

The available Zn content of soils of district Allahabad and Fatehpur ranged from 0.4 to 7.6ppm and 0.4 to 7.5ppm, respectively with mean value of 0.74ppm. The maximum mean (0.86pm) was recorded at Bahuwa block of Fatehpur whereas the minimum (0.67ppm) was recorded at Haswa block in Fatehpur. Soil is generally deficient in N, organic carbon and Zn, moderate in phosphorus and sufficient in potassium. A significant response of added Zn as zinc chelates can be obtained in this region. The upland soils of this region had 0.67 to 0.76ppm (mean) as compared with 0.76 to 0.86ppm (mean) under low land condition.

A field experiment was laid out with mustard variety T-9 in 2000-01 to study the effect of varying levels of S and Zn and their interaction S.D.I. research plots with normal doses of N, P, K, sulphur level @ 0, 20, 40 and 60 kg ha^{-1} through $\dot{S}$ and zinc levels @ 0, 5 and 10 kg ha^{-1} through ZnO, respectively were mixed in different combinations to study the growth

parameters viz. grain, stem and podhusks yields and the nutrient content and uptake of S and Zn in mustard grain.

The plant heights at 30, 60 and 90 DAS increased significantly with increasing levels of S and Zn. Influence of S and Zn interaction on plant height appeared non-significant. Data computed at 5% level of significance revealed that the application of S at 60kg ha^{-1} along with 10kg ha^{-1} of zinc was superior over other treatments.

The percentage increase of plant height and yield of mustard crop by different treatments over the control set has been worked out and presented in the following table V(a).

Table V(a)

Percentage increase of plant height and yield of mustard crop as compared to control set

Treatment	% INCREASE					
	Plant height			Grain yield	Stem yield	Podhusk yield
	30 DAS	60 DAS	90 DAS			
T_2	6.96	6.10	9.45	12.46	11.11	20.49
T_3	10.87	7.52	12.85	24.41	23.94	42.20
T_4	11.96	23.22	18.71	15.56	15.65	49.47
T_5	17.59	25.40	23.31	36.43	36.25	51.52
T_6	21.86	27.80	25.97	55.16	55.38	42.25
T_7	20.01	42.20	28.91	27.65	26.32	53.58
T_8	33.14	42.20	30.43	46.46	47.12	55.42
T_9	47.80	45.80	38.43	68.95	12.34	52.10
T_{10}	38.13	44.16	40.63	67.03	17.13	58.58
T_{11}	44.01	47.87	47.29	73.52	16.19	48.47
T_{12}	55.29	49.29	50.54	75.95	11.35	47.26

The primary and secondary branches of mustard crop was counted at two stages of growth viz. 1st at 60 D.A.S. and 2nd at harvesting period. The percentage increase of various treatments over the control has been tabulated in table V (b).

Table V(b)

Percentage increase of number of branches mustard crop as compared over the control set

Treatment	% INCREASE			
	60 D.A.S.		at harvesting	
	Primary branches	Secondary branches	Primary branches	Secondary branches
T_2	06	17.70	7.14	5.0
T_3	26	31.25	17.85	13.33
T_4	32	38.54	30.35	19.16
T_5	40	45.83	35.71	30.00
T_6	40	52.08	42.85	38.33
T_7	46	59.37	35.71	46.66
T_8	60	62.50	48.21	52.50
T_9	60	69.79	53.57	63.33
T_{10}	66	72.91	60.71	71.66
T_{11}	72	80.20	71.42	80.00
T_{12}	60	93.75	83.92	85.83

Similarly, S-uptake, Zn-uptake by mustard grains have been calculated and their percentage increase over the control was worked out and presented in table V (c). The oil content of mustard grain has also been included in the table.

Table IV (c)

Percentage increase of S content and its uptake, Zn content and its uptake and oil content by mustard grains over the control.

Treatment	S		Zn		Oil contents grain
	Content grain	Uptake grain	Content grain	Uptake grain	
T2	3.12	15.83	108.90	133.84	1.39
T3	4.68	30.06	196.03	267.19	3.03
T4	6.25	22.20	51.00	74.51	9.10
T5	7.81	45.55	180.04	279.86	3.12
T6	7.81	66.62	206.46	379.77	15.77
T7	9.37	38.15	74.00	122.51	17.33
T8	10.93	60.47	158.20	276.17	19.94
T9	12.50	88.87	212.56	429.12	21.85
T10	14.06	89.06	133.55	289.43	23.60
T11	15.62	98.51	184.86	394.87	24.37
T12	15.62	101.93	202.44	430.15	25.08

The soil samples were collected from each plot after the harvest of mustard crop and the composite sample for each treatment was processed for analysis for different nutrients for their total and available contents viz. N,P,K, S and Zn. The data containing soil contents have been presented in table in thesis.

The second field experiment was conducted during 2001-02 with Chickpea (cv. Pusa – 261) as the test crop using same S and Zn levels taken the for the previous mustard crop.

The height of the Chickpea crop as affected by different levels of S and Zn at 30,60,90 and 120 DAS. The height of plant increased by 24.4% to 32.8% over the control. Influence of S and Zn interaction on plant height appeared non-significant during 2001-02. Data computed at 5% level of significance, revealed that the application of 60 Kg S along with 10 Kg Zn ha^{-1} was superior over the other treatments on height of plants.

The S and Zn significantly influenced the number of branches per plant during the year 2001-02. On an average the number of branches per plant increased linearly and significantly with an increase in S and Zn doses upto 40 and 5 Kg levels respectively. The average number of branches ranged from 23.3 to 30.0 when the dose of S increased upto 60 kg ha^{-1} without zinc application. Whereas increases from 23.3 to 27.3% was noticed when the dose of Zn increased upto 10 kg ha^{-1} without S application.

The grain yield increased linearly and significantly upto 40 kg S and 5 Kg Zn ha^{-1} application and thereafter decreased upto 60 kg S and 10 kg Zn level. On an average the highest grain yield of 23.9 q ha^{-1} recorded at 40 kg S ha^{-1} was computed 26.4% higher than the lowest grain yield of 18.9 q ha^{-1} recorded at control set. The S application in comparison to Zn was of higher magnitude.

The highest straw yield 36.5 q ha^{-1} recorded at 60 Kg S ha^{-1} and was calculated 28.5% higher than the lowest straw yield of 28.4 q ha^{-1} recorded at control i.e. on sulphur application.

The uptake of N,P,K,S and Zn by chickpea crop was calculated and has been tabulated and mentioned in table 5(d). The percentage increase

over the control for the uptake of above mentioned nutrients and the crude protein were also recorded.

Table V (d)

Percentage increase of N,P,K,S and Zn uptake and protein content by chickpea grains over the control set.

Treatment	N	P	K	S	Zn	Crude Protein
T2	20.00	7.96	28.06	4.74	157.72	3.47
T3	26.72	9.56	31.34	1.45	166.65	7.94
T4	24.42	27.09	23.81	54.56	23.69	8.60
T5	56.62	44.48	62.53	80.10	210.79	15.56
T6	56.69	32.53	63.25	68.06	215.62	16.22
T7	40.70	45.68	46.23	87.04	38.95	12.08
T8	65.16	49.93	79.30	100.36	217.45	16.94
T9	63.30	38.11	79.14	94.16	217.96	16.61
T10	44.89	41.69	51.76	100.18	27.33	13.46
T11	58.83	40.37	72.13	101.82	177.25	17.27
T12	55.41	28.28	68.45	79.74	176.23	16.61

The soil samples were collected from each plot after the harvest of chickpea crop and the composite sample for each treatment was processed for analysis for different nutrients for their total and available content viz. N,P,K,S and Zn. The data containing soil contents have been presented in table in thesis.

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